SIGNATURE MEASUREMENT STANDARDS GROUP

SPECIAL REPORT

DEVELOPMENT OF ELECTRO-OPTICAL (EO) STANDARD PROCESSES FOR APPLICATION

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NAVAL UNDERSEA WARFARE CENTER DIVISION, NEWPORT
PACIFIC MISSILE RANGE FACILITY
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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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SPECIAL REPORT

DEVELOPMENT OF ELECTRO-OPTICAL (EO) STANDARD PROCESSES FOR APPLICATION

Prepared by

SIGNATURE MEASUREMENT STANDARDS GROUP (SMSG)

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PREFACE

This report presents the results of efforts of the Range Commanders Council (RCC) Signature Measurement Standards Group (SMSG) for completion of Task SMSG-18 and the publication of "*Development of Electro-optical (EO) Standard Processes for Application*." This document defines the process of characterizing the measurement capabilities of EO measurement systems, and establishes a demonstration program that verifies and quantifies the improvement in measurement capability that will result from implementing documented processes. The standard processes include calibration procedures, standard data reduction procedures to transform raw data to standard engineering unit data, standard terminology, and standard units of measure.

For development of this standard, the RCC gives special recognition to:

Task Lead: Mr. Jeffrey Burks: Associate Representative, SMSG
Air Force Research Laboratory (AFRL/RYS)

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ACRONYMS

AC	alternating current
ADC	analog-to-digital converter
AFB	Air Force Base
AFRL	Air Force Research Laboratory
AFRL/SNS	AFRL Signature Branch (office symbol)
AIS	automated information system
AL	accredited laboratory
AMTA	Antenna Measurement Techniques Association
ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATK	ATK Space Systems Inc. (reference to)
CASCO	Council Committee on Conformity Assessment (an ISO committee)
COTS	commercial-off-the-shelf
DAQ	data acquisition
DC	direct current
DoD	Department of Defense
EO	electro-optical
EO/IR	electro-optical/infrared
EOSPA	EO Standard Processes for Application
FOV	field of view
FPA	focal plane array
I/O	input/output
IAF	International Accreditation Forum
IAF-ILAC-ISO/CASCO	Joint Working Group on Image and Integrity of Conformity Assessment
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
ILAC	International Laboratory Accreditation Cooperation
IR	infrared
IRIG	Inter-range Instrumentation Group
ISO	International Organization for Standardization
IT	integration time
JWG	joint working group
LAN	local area network
LWIR	long-wavelength infrared
M&TE	measuring and test equipment
MAP	measurement assurance programs
MFO	measurement facility/organization
MSDS	Material Safety Data Sheets
MWIR	mid-wavelength infrared
NCSL	National Conference of Standards Laboratories (now known as NCSL International)
NEP	noise equivalent power

NIIRS	National Imagery Interpretability Rating Scale
NSL	National Standards Laboratory
NUC	non-uniformity correction
OMF	Optical Measurements Facility (at AFRL/R)
OOT	out-of-tolerance
PCB	printed circuit board
RCC	Range Commanders Council
RCS	radar cross section
RR	round robin
S/N	signal-to-noise
SI	International System of Units
SMSG	Signature Measurement Standards Group
SPP	standard practices and procedures
SRM	shared resource manager
TSPI	time-space-position information
UV	ultraviolet
WPAFB	Wright-Patterson AFB

CHAPTER 1

BACKGROUND

1.1 Summary

This report presents the results of an effort by the Signature Measurement Standards Group (SMSG) of the Range Commanders Council (RCC) to define and document standard processes to apply electro-optical (EO) measurement systems. The over-arching objective of this task, Task SMSG-19, as well as other yet to-be-defined tasks, is to develop an accreditation program for laboratories involved in collecting ultraviolet through infrared (IR) radiometric measurements.

In this document, the term electro-optical/infrared (EO/IR) is used to identify the community involved with collecting ultraviolet, visible, and infrared radiometric measurements in the electromagnet spectral region spanning 0.2 μm to 25 μm.

1.2 Approach for Developing the Accreditation Program

The envisioned accreditation program is being developed along lines similar to those followed by the radar cross section (RCS) community (Reference 1.11a). Part of the effort consists of modifying the evaluation criteria developed for the RCS certification program, which is based on the American National Standards Institute (ANSI Z540.1-1994, R2002) criteria (see Reference 1.11b). With modifications, the RCS *certification* program and the ANSI evaluation criteria were found to generally suit the EO/IR community. While the RCS certification program is based on the aforementioned ANSI standard, the SMSG recommends that future work focus on the design of an accreditation program based on ISO/IEC-17025 (Reference 1.11c). The 17025 standard, which is part of the ISO-9000 series and is more familiar to industry, replaced ISO Guide 25, which was the international equivalent to ANSI Z-540.

This effort defined, documented, and tested processes that can be standardized and applied to EO/IR measurement systems. The standard processes drafted during this effort define levels of characterization that are synonymous with levels of fidelity and the processes to meet those levels. The levels of characterization allow cost effective options to meet test requirements and to allow documentation of spiral improvement of capability. The standard processes include calibration procedures, standard data reduction procedures to transform raw data to standard engineering unit data, standard terminology, and standard units of measure.

1.3 Quality Documentation Book (The *Lab Book*)

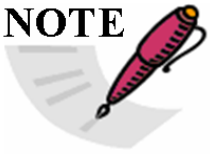
Employing material developed under this task and using the aforementioned RCS certification program as a guide, the Optical Measurements Facility (OMF) at the Air Force Research Laboratory (AFRL), Wright Patterson Air Force Base (AFB), developed a Quality Documentation Book. This book, commonly referred to as the *Lab Book*, serves as a demonstration of the processes required for accreditation of the EO/IR measurement capabilities.

The OMF conducted a self-assessment and the results were independently evaluated by two outside organizations.

The evaluation criteria applied during the OMF assessments, presented in Chapter 2, were subsequently modified to eliminate redundancy and ambiguity, and to make the criteria easier to interpret. The modified criteria, provided in Chapter 3, reflect lessons learned from three assessments by different groups; however, they were applied to the same AFRL *Lab Book*. One recommendation resulting from this effort is that the evaluation criteria should be tested more thoroughly and broadly at facilities having significantly different functions and capabilities.

During the course of the Task SMSG-18 effort, a survey was designed, developed, disseminated, collated, and analyzed. The survey form used and the subsequent results and analyses are presented at Chapter 4 and Chapter 5, respectively.

The draft standard for characterization of EO/IR measurement facilities and a draft handbook for conducting EO/IR measurements are at Chapter 6 and Chapter 7, respectively. The information in Chapter 6 and Chapter 7, plus the work product from Task SMSG-19 (RCC document 809-10, *Standards and Procedures for Application of Radiometric Sensors,* Reference 1.11d), should be considered by the broader EO/IR measurements community as foundations (however imperfect) for a full-fledged accreditation program.

NOTE 	The work presented in this report is not intended to be a final product that represents the full spectrum of references needed for an accreditation program that would be consistent with best practices and those documented by the ISO. Rather, the material presented here is intended to be the basis for further review, dialog, and refinement by the EO/IR measurements community.

1.4 Task Overview

The original scope of the effort covered by Task SMSG-18 addressed the need to define and document standard processes for electro-optical (EO) measurement systems.[1] Ultimately, the efforts undertaken by this task would be applied to the establishment of an accreditation program for EO/IR measurement capabilities.

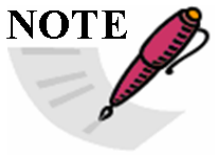
The precedence for developing an accreditation program for EO/IR measurement capabilities lies in another effort by the SMSG between 1999 and 2001 that developed a certification process and standard for the RCS community (Reference 1.11a). That certification process was based on an ANSI standard that applies to measurements made by calibration laboratories (Reference 1.11b). The ANSI standard was the United States (U.S.) equivalent to an ISO guide that was subsequently replaced by a newer standard (Reference 1.11c).

[1] In this document, the terms *electro-optical (EO)* and *electro-optical/infrared (EO/IR)* are used interchangeably and generically are used to identify the community involved with collecting ultraviolet, visible, and infrared radiometric measurements in the electromagnet spectral region spanning 0.2 μm to 25 μm.

Some members of the SMSG familiar with both the RCS and the EO/IR measurements community recommended that the EO/IR community follow an approach similar to the one used by the RCS. While the RCS measurement community is diverse, and the demonstration program that was developed and executed under SMSG auspices addressed some of that diversity, the EO/IR community is even more diverse. Unlike RCS measurements, which are overwhelmingly driven by the military, EO/IR measurements have a much wider base of practitioners and consumers than just the military. This wider base includes the military and civil agencies like the National Aeronautics and Space Administration (NASA), the National Institute of Standards and Technology (NIST), the Department of Agriculture, as well as many industries and everyday consumer products.

The Task SMSG-18 products documented in this report are part of a larger multi-year evolutionary effort that includes Task SMSG-19 (see Reference 1.11d), as well as tasks yet to be more fully defined and executed. Because of the aforementioned diversity of the EO/IR measurements community, the level of effort to achieve consensus by the EO/IR measurements community is significantly greater than that of the RCS measurements community. For example, clarification is even required for some of the most basic terminology such as certification and accreditation.[2]

One goal of Task SMSG-18 was to establish standardized processes that would define levels of characterization that are synonymous with levels of fidelity and the processes needed to meet those characterization levels. By establishing and permitting different levels of characterization, cost effective options to meet test requirements would allow for the documentation of spiral improvements in capabilities at any given measurement facility. The standard processes to be defined included calibration procedures, standard data reduction procedures to transform raw data to standard engineering unit data, and standard terminology and units of measure.

	On the above point regarding standard terminology and units of measure, the terminology and units expressed herein are not as expansive as those found in Reference 1.11d (from Task SMSG-19).

[2] Since the early 1990s, there has been broad confusion with respect to the terms *accreditation* and *certification* as they may be applied to formal programs that seek to document compliance with standards. The long-running confusion was addressed by the International Organization for Standards (ISO) in 1996 when it published *ISO/IEC Guide 2:1996*, which sets out the definitions specifically related to standardization, certification, and laboratory accreditation, and again in December 2002 with a special memo on the topic (See Reference 4). Simply summarized, *accreditation* applies to the competence of organizations or persons while *certification* applies to products, processes, or services. Even with these clarifications, issues still arise. For accreditation, an *authoritative body* gives formal recognition that a body (organization) or person is competent to carry out specific tasks. For certification, a *third party* gives written assurance that a product, process, or service conforms to specified requirements. In RCC 804-01, the term *certification* is used and *a third party* (not an *authoritative body*) gives written assurance that a *body* (not a *product*, *process*, or *service*) is competent to perform radar cross section measurements in the context of the facility employed. In this document, the term *accreditation* is preferred because the procedures envisioned by the authors of this proposed standard more closely align with the ISO definition for that term.

The efforts undertaken through Task SMSG-18 resulted in several draft/baseline documents that will support the establishment of an accreditation program for laboratories involved in collecting ultraviolet through infrared radiometric measurements. Given the many challenges encountered, such as a funding reduction and a disruption due to contractual issues, there was still a great deal of work accomplished under this task. The challenges, coupled with the large size and scope of establishing a fully vetted accreditation program, means much work remains to be done. Because of the diversity, and the relatively small number of participants in this task, this document should not be construed as the final word on accrediting facilities or organizations engaged in EO/IR measurements. Instead, this document provides some of the basic building blocks of an accreditation program.

Although the material presented herein may appear to be relatively complete, a broad community effort is needed to verify and validate the ideas presented. Therefore, significant changes are anticipated, but because the application areas are so broad and complex, establishing a single process with a single set of evaluation criteria may not be possible.

1.4.1 Actions Taken to Address the SMSG-18 Requirements. In summary, the SMSG-18 goals were to address the task requirements by:

a. Establishing or adopting baseline evaluation criteria (Chapter 2).
b. Drafting criteria for EO measurement capabilities evaluation consistent with published standards for measurement facilities (Chapter 3).
c. Developing a survey (Chapter 4).
d. Distributing the survey and collecting results.
e. Compiling and presenting the survey results (Chapter 5).
f. Drafting a standard for EO measurement process (Chapter 6).
g. Drafting a handbook for characterizing the measurement capabilities of EO/IR measurement systems (Chapter 7).
h. Production of this final report.

When task SMSG-18 began in earnest, the task lead contracted for support. During the first year of support, the contractor underwent both organizational and personnel changes, causing some diversions and realignments of tasks and priorities. Nevertheless, much work was accomplished toward accomplishing the above stated goals. The task was originally planned as a two-year-plus funded project under the RCC Omnibus Contract, funding in the third year was reduced to zero. Those factors caused the SMSG to reassess and to some extent adjust the methods and means to produce products that would be useful to the broader EO/IR community.

The RCC SMSG selected the AFRL/RX OMF as a pilot facility for developing and testing some of the elements for an accreditation program for measurements conducted in the EO/IR spectral region. Lessons learned during the pilot effort were used to modify the draft EO/IR accreditation program materials presented in this report.

The purpose of the OMF is to measure, correlate, and analyze the optical behavior of materials. The OMF instruments operate in the ultraviolet through the infrared wavelength region.

1.4.2 Core OMF Optical Measurement Instruments. The core OMF optical measurement instruments include:

a. Ultraviolet-visible-near-infrared spectrometer with directional hemispherical reflectance attachments.
b. Infrared spectrometer with directional-hemispherical reflectance and directional-emittance attachments.
c. Laser and broadband bidirectional-reflectance scatterometers.

The OMF prepared a draft *Lab Book* using the ANSI Z540.1-1994 (R2002) standard that documents the measurement procedures, instrument error characterization, and quality control procedures used at the facility. This same standard has been used by the RCC SMSG for the RCS Range Accreditation Program.

The focus of this report is on the evaluation process and the establishment of evaluation criteria. Both the independent assessments and the self-assessment show clearly that a significant amount of work remains to be done before the OMF could achieve full compliance. Though achieving a great deal through this exercise, becoming fully compliant is not a current objective for the OMF. However, full compliance may become a goal as the accreditation program matures and the OMF, like other facilities/organizations, becomes more familiar with the overall program.

A good framework has been developed, but further development is needed before undergoing a thorough compliance review. The management of the OMF has determined that they are not seeking formal accreditation, but they are interested in developing a better-documented facility calibration and quality control process. Such a process will give assurance to their customers that sound measurement practices and error assessments are being performed. A reasonable foundation for developing and implementing a quality assurance and control plan for their laboratory is provided by ANSI-Z-540.1-1994 (R2002).

The evaluations conducted on the OMF represented an initial look at the OMF processes from the perspective of ANSI-Z-540.1-1994 (R2002). The RCC/SMSG had two primary objectives for this evaluation. They were:

a. Perform a quality system assessment.
b. Strictly follow (as much as feasible) the certification/accreditation process and evaluation criteria to provide lessons learned and opportunities for improvement on future projects.

1.5 Evolution of the Evaluation Criteria

The OMF conducted a self-assessment by using their OMF *Lab Book*. Additionally, two independent assessments were conducted. Evaluation of the *Lab Book* followed the evaluation criteria given in Chapter 2, which were virtually identical to those developed by the SMSG for the standard that has been applied to RCS measurement facilities. The criteria employed for assessing the OMF were subsequently modified based on lessons-learned during the three

assessments. The modified criteria form the final recommended criteria under this effort and are provided in Chapter 3. The modifications were suggested to remove ambiguous, duplicate, or irrelevant requirements, and to make some of the language more readable. The evaluators collectively recommended further review of the criteria presented in Chapter 3 by a broader collection of EO/IR subject matter experts before final adoption as part of an accreditation program. Even if the EO/IR community elects to follow a path defined by ISO/IEC 17025, the modified criteria should be considered as a starting point. (See paragraph 1.10, Conclusions and Recommendations for more details.)

As was implemented by a substantial number of RCS measurement facilities, the OMF *Lab Book* is web-based and interactive in nature, with hyperlinks to relevant sections and reference materials. All of the links tested worked and linked the evaluator to the correct content. No on-site review was performed, so none of the on-site review criteria was evaluated.

As has proven to be typical in the RCS measurement facilities certification program, the initial evaluation of the OMF showed that the facility made good progress, but had not achieved passing scores. That result is actually the norm. Because it was recognized in the RCS program that facilities never managed to achieve a passing score at the mid-term evaluation, the process evolved such that the communications between the evaluators and the facility are best conduced on a continuous basis so that improvements can be made and changes implemented as weaknesses are uncovered. As a minimum, after the highest priority sections are reviewed, a mid-term report is issued to the facility so that it may begin tackling those criteria found to be less than satisfactory. The recommended practice is that the evaluators hold regularly scheduled teleconferences with the facility during the review process. The teleconference helps to prevent surprises, provides the facility/organization with an opportunity to clarify requirements, and gives an opportunity to clarify the methodologies for meeting requirements.

An important goal of Task SMSG-18 is wide dissemination of this final report. Following the precedence set by the RCS community, and as is typically followed in the ISO community, the results of evaluations are confidential in nature. Generally, the intimate details found during such evaluations are not reported (e.g., scores or specific comments about how individual criterion were (or were not) addressed). An evaluated organization may elect to publicly share its evaluation results. As the OMF is a U.S. government facility and various public-release restrictions apply to information about such facilities, we present in Chapter 2 only the criteria and some of notes that were provided by the evaluators, but only to the extent such notes illuminate issues that other facilities might encounter.

1.6 Recommended Evaluation Criteria

The ANSI Z-540.1-1994 (R2002) standard and the international equivalent (ISO Guide 25) have been superseded by ISO/IEC-17025 and its U.S. equivalent, ANSI/NCSL Z540.3-2006. ISO/IEC-17025 differs significantly in organization, but contains very similar quality management techniques and criteria. Changes were made to better align the newer standard with other ISO quality systems standards and guidance. The primary reason the OMF elected to use the outdated ANSI Z540.1-1994 (R2002) standard is due to the availability of the evaluation criteria developed for it by the DoD RCS Certification community. The National Conference of Standards Laboratories (NCSL) Handbook for ANSI Z540.1-1994 contains

suggested evaluation factors written in the form of declarative statements that are very broad in scope. The RCS community rewrote those relevant evaluation factors in an interrogative format that was customized for the RCS range environment. The OMF used the DoD RCS Certification criteria as the basis for their own *Optical Properties Laboratory Book* and evaluation criteria by adapting them to the EO/IR laboratory setting.

With some effort, a similar set of evaluation criteria could be written for ISO-17025. This could be beneficial in the future, since ISO-17025, and the ISO-9000 series of which it is a part, are more familiar to industry and could add to the prestige and economics of certification. For the present, the quality system described in ANSI Z540.1-1994 (R2002) meets the needs of both the RCS and the EO/IR accreditation programs. Ultimately, the recommendation is for the EO/IR community to employ ISO/IEC-17025.

1.7 Survey

The contractor[3] supporting Task SMSG-18 distributed the first draft of what was called the *Development of EO Standard Processes for Application (EOSPA)* with survey/questionnaire to the organizations identified by the RCC to solicit feedback. The survey/questionnaire included questions that were intended to help identify an initial set of ranges that would be willing to demonstrate the standard procedures to be documented in the EOSPA draft. Eleven surveys were completed and collected after three rounds of survey distributions.

The first version of the draft of EOSPA in the format of a Microsoft Word® document with survey and instructions attached was distributed to about 10 to 15 attendees during an SMSG meeting held in October 17-18, 2006. Unfortunately, none of the organizations surveyed sent back feedback by the deadline. To make responding to the survey easier, a second version in the form of an Microsoft Excel® spreadsheet was completed on November 27, 2006. The survey was distributed again to the known EO/IR ranges and SMSG members. Feedback from four groups was collected in the second round but none of them included sample procedures or reports. One of the respondents was not willing to share its responses with the broader community, so those responses were not included in the tally. To solicit more feedbacks, the SMSG modified and redistributed the survey via e-mail during January 10-11, 2007 to about 110 contacts involved in EO/IR measurements. Follow-up telephone calls were made to all the contacts. Feedback from seven groups was collected but none of them included sample procedures or reports. Finally, in an effort to collect sample procedures and reports, e-mail requests and phone calls were made during March 8-19, 2007 to the organizations who responded to the survey. This effort still did not result in any sample procedures or reports. Some organizations informed the contractor that the procedures and reports were for their internal use only. Their management did not approve the request for distribution. Other organizations simply said that they did not have any.

[3] Following task initiation, and subsequent to some contractual issues being resolved, the contractor that was awarded the task to support AFRL on Task SMSG-18, Mission Research Corporation, was subsequently bought by Alliant TechSystems Inc., now known as ATK.

Despite these challenges, the survey did result in the collection of a significant amount of information, particularly as relates to instrumentation. The survey is provided as Chapter 4, with the results provided, without attribution to the participants, in Chapter 5.

1.8 Draft Documentation Standard

Though the effort to collect information from the community proved to be less successful than was desired, the contractor developed and delivered a draft document, *Electro-Optical Standard for Applications*, in October 2006.

That document provided a draft standard for characterizing the measurement capabilities of EO/IR measurement systems in the hope that it would assist in the establishment of a demonstration program to verify and quantify the improvement in measurement capabilities that would result from implementing documented standards. The draft standard set out to define levels of information content that are synonymous with levels of knowledge and expertise and the requirements needed to meet those levels. For example, the lowest level would be capable of providing qualitative information. A middle level might provide relative quantitative information. The highest level would incorporate both lower levels and would be able to provide absolute quantitative information with specified measurement uncertainties. The levels allowed were intended to specify cost effective options to meet preset test requirements.

The document, presented in Chapter 6, *Draft Document Standards for Characterizing the Measurement Capabilities of EO/IR Measurement Systems*, provides a draft standard for planning, executing, and reporting signature measurements. It also describes the resources available to the EO/IR range community and recommends procedures to help testers make efficient, effective use of instrumentation. Included are:

a. EO instrument characterization and calibration procedures.
b. Standard data reduction procedures to transform raw data to engineering units.
c. Measurement uncertainty analysis.
d. Standard terminology and units of measure (and see Reference 1.11d).

As with the modified evaluation criteria, the draft standard is intended to be a starting point for discussion and consensus building across the EO/IR measurements community.

1.9 Draft Handbook for Electro-optical Measurements

Out of the various sub-tasks that comprised Task SMSG-18, a draft handbook was born. The draft handbook was based, in part, on RCC 804-01 (Reference 1.11a) and IRIG Standard RCC 802-98, Tactical Missile Signatures Measurement Standard and Definitions (Reference 1.11i). The draft handbook, presented in Chapter 7, is intended to assist SMSG members and others engaged in electro-optical and infrared signature measurements by documenting standard procedures. The overall structure and language used in the draft handbook parallels that of the Handbook for the Interpretation and Application of ANSI/ NCSL Z540-1-1994.

As with the modified evaluation criteria and the draft standard, the draft handbook is intended to be a part of the discussion and consensus building across the EO/IR measurements community as it moves forward in developing an accreditation program.

1.10 Conclusions and Recommendations

Although completing Task SMSG-18 was difficult, the resulting reference material was substantial. That material, much of which is collected in this final report, can serve as baseline documents, or as points of departure, for an expanded, robust dialog among EO/IR measurement community members. The desire is that the fruits of the long and arduous task of completing Task SMSG-18 support a community-wide accreditation program, though much collaborative work remains to be accomplished to achieve that end.

The OMF made significant progress toward reaching their goal of having an ANSI Z540.1-1994 (R2002)-compliant calibration and quality control process. This evaluation has identified the specific areas where the OMF needs to improve or develop processes in order to achieve that goal. They developed a comprehensive web-based laboratory book that is interactive in nature, has hyper-links to relevant sections and reference materials, and is a good example for other EO/IR laboratories. A great deal of effort has gone into developing their processes and we recommend that the OMF continue to improve their Laboratory Book to the point it can be submitted for formal compliance review.

The recommendation of the participants is that evaluation criteria based on either ANSI/NCSL Z540.3-2006 or the ISO-17025 be adopted by the SMSG and RCC for the EO/IR laboratory community. Alternatively, and as a minimum, evaluation criteria based on ANSI Z540.1-1994 (R2002), as presented in Chapter 3, could be used, but because of the breadth and diversity of facilities/organizations that might follow this program, the more contemporary standards would likely be more palatable.

The recommendation of the participants is that the evaluation criteria in Chapter 3 be reviewed and additional testing of those criteria by multiple facilities occurs before finalizing the criteria. A multi-facility test of the process and criteria would follow the same path as the RCS certification program, in which three very different facilities were employed to test the process and criteria. After more broadly tested criteria have been refined, they should be presented to the EO/IR community in a document including clearly written definitions of the criteria. In order to reach a broad consensus, the document should also include the background of how the criteria were evolved.

The participants further recommend that the percentages of Satisfactory, Needs Improvement, and Unsatisfactory be more widely assessed to finalize how they will be applied, especially given the recommendation that there be different levels of measurement characterization (see Chapter 7, Draft Handbook for Electro-Optical Measurements).

Finally, this report has not addressed the administrative procedures (such as what entity will administer the program, the initial application for review, reviewer's qualifications, and panel appointment) for a formal accreditation program. We recommend the SMSG undertake a task to establish those elements of the accreditation program.

1.11 References

a. Radar Cross Section (RCS) Certification for Static and Dynamic RCS Measurement Facilities, Volume 1 Certification Process, RCC Document 804-01, Vol. 1 (Revised Aug 2001), Secretariat, Range Commanders Council, U. S. Army White Sands Missile Range, New Mexico 88002-5110.

b. ANSI-Z-540.1-1994 (R2002) Calibration Laboratories and Measuring and Test Equipment – General Requirements.

c. ISO/IEC 17025:2005(E), General Requirements for the Competence of Testing and Calibration Laboratories.

d. Standards and Procedures for Application of Radiometric Sensors, Range Commanders Council Document No. 809-10, 1 July 2010.

e. IAF/ILAC JWG/12, Objectives and Roles of "Accreditation" and "Certification" of Laboratories, Joint Working Group on Image and Integrity of Conformity Assessment (IAF-ILAC-ISO/CASCO), December 2002.

f. AFRL/RX Optical Properties Lab Book for the Optical Measurements Facility, CD, July 2009.

g. Memo: Development of an Optical Properties Lab Book for the AFRL/RX Optical Measurements Facility, W. Lynn, General Dynamics AIS, J. Costantino, AFRL/RXPJ, July 2009.

h. AFRL/RX Optical Measurements Facility, Optical Properties Laboratory Book, Content and Evaluation Criteria.

i. Tactical Missile Signatures Measurement Standard and Definitions, IRIG Standard RCC 802-98, Range Commanders Council, December 1998.

CHAPTER 2

EVALUATION CRITERIA APPLIED TO THE OPTICAL MEASUREMENTS FACILITY (OMF) "LAB BOOK"

2.1 Priority Ordering of Evaluation Criteria

The evaluation criteria are presented below in sections grouped in *priority* order, not in numerical order. The criteria are prioritized as follows:

Priority 1. Those elements of a measurements quality program having direct bearing on the quality of the measurements being taken and reported.

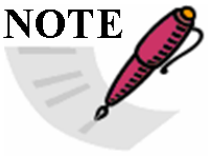
Priority 2. Those elements of a measurements quality program having indirect bearing on the quality of the measurements being taken and reported.

Priority 3. Administrative elements of a measurements quality program, which do not directly nor indirectly impact the quality of the measurements taken and reported, but which do reflect good management practices that, in-turn, enhance the overall quality measurement program.

2.2 Criteria Assessments

The following assessments are as follows:

S Satisfactory if the requirement is met fully.
N Needs Improvement if the requirement is met to some reasonable degree.
U Unsatisfactory if the requirement is barely met or not met at all.
N/A Not Applicable if the requirement is not relevant to the facility under evaluation.

	The OMF self-assessment was rated as either being met satisfactorily (a check mark) or deficient (D). This approach may suffice for an initial internal assessment, but may yield surprising results when an external reviewer utilizes a broader assessment scale.

To determine an overall score by priority, the scheme in Table 2-1 was applied.

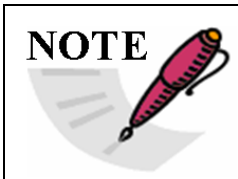
TABLE 2-1. COMPOSITION OF PASSING SCORES

Priority	Evaluation Criteria	Notes
1	S ≥ 85%	To achieve accreditation, 85% or more of the Priority 1 criteria must be scored Satisfactory, with the rest being scored Needs Improvement. No Unsatisfactory (and no Not Applicable) scores are permitted for Priority 1 Sections.
	N ≤ 15%	
	U = 0%	
2	S ≥ 75%	To achieve accreditation, 75% or more of the applicable* Priority 2 criteria must be scored Satisfactory; no more than 10% of the criteria can be rated Unsatisfactory (with the balance being Needs Improvement).
	N ≤ Balance	
	U ≤ 10%	
3	S ≥ 75%	To achieve accreditation, 75% or more of the applicable* Priority 3 criteria must be scored Satisfactory; no more than 10% of the criteria can be rated Unsatisfactory (with the balance being Needs Improvement).
	N ≤ Balance	
	U ≤ 10%	

* Some criteria in Priority 2 and Priority 3 sections may be determined by a measurement facility to be Not Applicable. The scoring percentages are based on the number of applicable criteria, not the total number of criteria.

TABLE 2-2. EVALUATION CRITERIA APPLIED TO THE OPTICAL MEASUREMENTS FACILITY (OMF) LAB BOOK

Priority	*Lab Book* Section No.	*Lab Book* Section Title
1 ¶ 2.3.1	9	Measurement Traceability and Calibration
	10	Measurement and Calibration Procedures
	11	Handling of Calibration Items
	17	Interlaboratory Comparison Programs
	18	Data Processing Procedures
	19	Laboratory-Specific Calibration Uncertainty
2 ¶ 2.3.2	5	Quality System, Audit, and Review
	8	Equipment and Reference Materials
	13	Certificates and Reports
	20	Ongoing Research, Planned Improvements
3 ¶ 2.3.3	1	Introduction and Endorsement
	2	References
	3	Glossary
	4	Organization and Management Structure
	6	Personnel
	7	Accommodation and Environment
	12	Record Keeping
	14	Subcontracting Records
	15	Outside Support Services and Suppliers
	16	Complaints



The numbering system for paragraph 2.3.1, paragraph 2.3.2, and paragraph 2.3.3 follows the section numbering of the OMF *Lab Book*, but is presented here in the priority order shown in Table 2-2. Likewise, the formatting for these paragraphs follows that of the OMF *Lab Book*.

2.3.1 Priority 1 Sections

SECTION 9 – MEASUREMENT TRACEABILITY AND CALIBRATION (PRIORITY 1)

This section should complement Section 8 as it specifically relates to primary optical properties calibration. The laboratory will document its calibration program that ensures all equipment critical to optical properties measurement calibrations operates within certified performance limits. Equipment and system calibration intervals should be clearly established. Whenever possible, traceability of system components and of total system calibration to a national standard should be referenced. The system configuration used in optical properties calibrations should be tracked using the method documented in Section 8. The system configuration used in inter-laboratory comparisons should be clearly documented together with

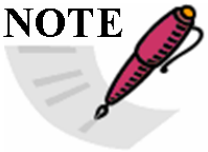
the results of calibration comparisons. System components tracked under *Lab Book* Section 8 need only be referenced here.

Note. Z540 Section 9.5 is found in laboratory book (*Lab Book)* Section 11.

Evaluation Criteria:

9.1: Does the laboratory have an established and documented program to ensure that its calibration program supports the stated calibration performance of its optical properties measurement system(s)?

9.2: Is the optical properties laboratory calibration process traceable to a published (MATA, IEEE, etc.) calibration artifact standard or other national standard (when developed)?

	Under normal circumstances, optical properties measurement systems are calibrated as a total end-to-end system. In special test cases where specific end-to-end calibration measurements are not the norm, Sections 9.3, 9.4, and 9.6 must be addressed for these cases.

9.3: Does the laboratory measurement and calibration program include a top-level schedule for calibration intervals for each piece of test equipment used to assess system performance?

9.4: Is there documentary evidence the top-level schedule (9.3) is being rigorously followed?

9.6: Does the laboratory have a documented program to monitor test equipment and/or calibration artifacts between scheduled calibrations and verifications?

9.7: When the laboratory participates in inter-laboratory comparisons (see 5.6), is the laboratory optical properties system configuration employed in those comparisons clearly documented?

On-site Review: For the primary calibration artifacts, are sample *acceptable* calibrations or verification records available within the laboratory book?

SECTION 10 – MEASUREMENT AND CALIBRATION PROCEDURES (PRIORITY 1)

Both measurement and calibration procedures should be fully documented. Separate documentation should be available for the measurement and calibration of directional-hemispherical reflectance, hemispherical-directional reflectance, and the bidirectional reflectance distribution function. Procedures for deriving or assigning an optical property value to a primary target using "transfer" calibration standards should be documented in this section. Calibration and measurement results to support the validity of procedures used should be displayed or referenced. The validity of such results should be supported by stated uncertainty bounds obtained through well-defined uncertainty procedures appropriately referenced here or in Section 19. Calibration intervals should be clearly established.

Note: The numbering/lettering sequence below follows Z540.

Evaluation Criteria:

10.1: Does the laboratory have documented system-wide calibration procedures?

10.2a: Are separate calibration and measurement procedures for each major measurement system or for each type of measurement conducted available?

10.2b: Are the calibration measurement procedures consistent with the accuracy required for each type of calibration measurement (as defined in the uncertainty analysis in Section 19)?

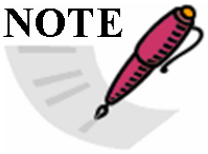
10.3: Is there documentation on the procedures for deriving or assigning optical property values for a measured target by using transfer standards?

10.4: Are system-wide calibrations scheduled on an appropriate cycle for the measurement system? Is this cycle defined? Is there evidence they are being performed when scheduled? Are the results of system-wide calibrations included or referenced in this section? Are these calibrations provided to the customer as part of their normal data report?

Calibration schedule is not discussed in this section although it may be described to some extent in section 5.

10.5: If sampling is included as a part of calibration or measurements, is documentation available that describes the procedures and applied statistical techniques employed? Detailed data processing implementations may be provided/discussed in Section 18, if applicable.

10.6: Do the results of acceptable system-wide calibrations support the uncertainty bounds established in Section 19?

NOTE 	Computers are currently an integral part of every optical properties laboratory. Since computers are used to record, store, retrieve, and process information, certain processes, procedures, and documentation need to be made available to the operator. Normal user manuals are crucial, and on-line "help" features of commercial off-the-shelf (COTS) software will fulfill a large portion of the requirements to follow. Specialized software written exclusively for laboratory data acquisition and processing requires equally thorough documentation.

10.7a: For (any) computer software used to acquire and/or store the raw optical data, is there an available user manual(s), either as automated help files or as a separate document(s), which describes the correct operation and use of the software? If the manual is not embedded in the laboratory book, is the physical location of the documentation clearly identified?

10.7b1: For computer software used to store (locally or on a network) or transmit from one network location to another, are appropriate users manuals and/or COTS help files available?

10.7b2: Is there a database or other appropriate tracking list of the computer program(s) that are used in the end-to-end data acquisition, transmission, and processing steps?

10.7b3: For computer software used to process the raw data files into final data products, are appropriate user manuals and/or COTS help files available? (This requirement may be satisfied one of two ways. If specifically written users manuals have detailed specific examples,

these can be used. If such specific examples do not exist, the requirement can be made by appending sample "step-by-step" processes that, if followed, produce the final data products.)

10.7c1:Is there an assigned computer support and/or network administrator available to maintain computer equipment used in the laboratory data acquisition and processing?

Cross-reference with Section 6, Personnel. Is there an IT person on staff, or is there a support organization that provides IT support?

10.7c2:Is there a diagram of the local area network within the laboratory, if applicable?

10.7d: Are critical environmental and/or operating procedures monitored to maintain the stated calibration accuracy and/or stay within the published calibration uncertainty of Section 19?

10.7e: Are there procedures that ensure security of the data to prevent the unauthorized or inadvertent access, manipulation, or destruction of computer data or records?

Note: An approved network automated information system (AIS) or standard practices and procedures (SPP) plan will generally satisfy this requirement. If the AIS/SPP is not electronically available in the laboratory book, its physical location must be precisely identified.

On-site Review: Request the laboratory manager perform a system-wide calibration. Verify that the documented procedures are followed by laboratory technicians.
On-site Review: Compare the results of the system-wide calibration with the historical records found in Sections 12, 13, and/or 19. Are the results within the stated calibration uncertainty limits?
On-site Review: Ask a technician if the observed documented procedures are up to date. Ask when the procedures were last reviewed for completeness and accuracy.

SECTION 11 – HANDLING OF CALIBRATION ITEMS (PRIORITY 1)
This section should summarize how primary calibration items are protected during storage, handling, and use. Mechanical tolerance certificates or techniques for verifying tolerances of primary standards are appropriately placed in this section.

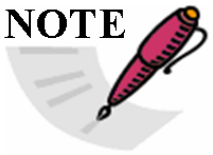
Evaluation Criteria:
11.1: Does the laboratory have a system for uniquely identifying primary calibration artifacts?

11.2: Does the laboratory have a system for assessing the mechanical tolerances and electrical conductivity of the primary calibration artifacts upon initial receipt? Are visual inspections performed on the calibration artifacts as part of the calibration process? Is there a stated procedure for reacting to artifacts found, suspected to be damaged, or suspected to be out of tolerance? (A mechanical test and/or measurement certificate will satisfy the initial receipt requirement.)

11.3: Does the laboratory have documented procedures and appropriate facilities to avoid deterioration or damage to calibration artifacts during storage, handling, preparation, and calibration?

Note: 11.3 also satisfies Z540 Section 9.5.

11.4: Does the laboratory book identify the exact location of the calibration artifact standard when not in use?

NOTE 	The biggest threat posed to a standard optical properties reference material (Spectralon reference, front-surfaced mirror, etc.) is physical damage. Most calibration reference materials can be contaminated without any visual indication. Therefore, it makes sense to store the calibration artifacts in well-identified, clean storage devices.

11.5: Does the laboratory take reasonable and appropriate measures to protect the calibration artifact(s) when not in use? Are there documented procedures for reporting suspected damage to a calibration artifact(s)? If the artifacts are repaired or replaced, are the procedures of 11.2 followed for the (repaired or replaced) unit?

11.6: If the primary calibration artifacts employed by the laboratory are used in any capacity other than to ensure the performance of the optical properties measurement system(s), do such uses invalidate or degrade the calibration artifacts?

On-site Review: Perform a visual inspection of the laboratory calibration artifacts to determine whether the conditions, procedures, and facilities assessed in 11.1 through 11.5 are as stated in the laboratory book.

SECTION 17 – INTERLABORATORY COMPARISON PROGRAMS (PRIORITY 1)
This section shall include the organization's policy regarding inter-laboratory comparisons. Records of participation in calibration inter-laboratory comparisons, the results obtained, and conclusions drawn from such studies are to be presented or referenced here. If the information is already included in Section 10, a reference to Section 10 is adequate. It is expected that inter-laboratory comparisons will be used regularly to improve measurement and calibration quality at the laboratory. An inter-laboratory comparison schedule should be provided.

Note: Participation in a national inter-laboratory comparison study is required for accreditation.

Evaluation Criteria:
17.1: Does the laboratory have a documented policy on inter-laboratory comparisons?

17.2: Does the laboratory participate in an inter-laboratory calibration comparison program at the national level?

17.3: Are the results of the inter-laboratory calibration comparisons of Section 17.2 available for customer review?

17.4: Are the results of the inter-laboratory comparisons used to evaluate and improve laboratory operations?

On-site Review: Review the laboratory documented inter-laboratory comparison policy. Is the available data current? Does the laboratory have a schedule for participation in inter-laboratory comparisons?

On-site Review: Ask the laboratory technical manager how the results of the inter-laboratory comparisons are applied to improving the quality of their measurements.

SECTION 18 – DATA PROCESSING PROCEDURES (PRIORITY 1)
Important details of processing measurement and calibration data should be documented here. Sample results of processing should be included. Standard data processing procedures should be referenced, and the validity of innovative processing should be documented. To evaluate the validity of its data processing procedures, the laboratory should use a standard data set acceptable to the optical properties industry. This standard data set should be used by the laboratory to perform inter-laboratory comparison of its processing algorithms with those used by other laboratories. This section should strongly support and complement the material in Section 17 above.

Evaluation Criteria:
18.1: Does the laboratory have all primary optical properties data processing procedures documented?

18.2: Have the data processing modules been validated with a standard data set to ensure the correctness of the algorithms employed?

18.3: Are the results of data processing compared against known quantities or standards to verify accuracy of the measurement and data processing process?

On-site Review: Is there a procedure to collect, determine, and validate all customer data processing requirements, to include such key items as specific formats, parameters, and quantities? Is there a procedure for translating user requirements into the specific procedures to collect the data identified by the customer?
On-site Review: Are procedures in place for validating the data in (near) real-time to ensure the proper data is being collected?
On-site Review: Ask a laboratory technician to process a file from a standard data set and compare the results to those known to be correct.
On-site Review: Ask the laboratory technical manager how new or improved data processing algorithms are validated.
On-site Review: Review the results of any inter-laboratory data processing comparisons. Are these results available to laboratory customers?

SECTION 19 – LABORATORY-SPECIFIC CALIBRATION UNCERTAINTY ANALYSIS (PRIORITY 1)
Policies and procedures for establishing laboratory uncertainties need to be completely documented or referenced here. A sample uncertainty table together with system parameters or other adequate uncertainty methods should be linked or available in this section. One approach to satisfy this requirement is the "Report of Measurement" described by B. M. Welsh and B. M. Kent in "An RCS Uncertainty Analysis and Calibration Certificate for AFRL Calibration Cylinder," Year 2000 Antenna Measurement Techniques Association (AMTA) Symposium, Philadelphia, PA. Any system parameters should be displayed here. Any scientifically based uncertainty analysis is acceptable, providing all appropriate assumptions and/or exclusions regarding the parameters comprising the analysis are clearly documented.

Evaluation Criteria:
19.1: Does the laboratory have a policy for the development and use of a calibration uncertainty analysis? (Alternate location for Section 5.2u.)

19.2: For the primary calibration standard(s) used by the laboratory, is there a nominal optical properties measurement with estimated uncertainties in either graphical or tabular form for that standard?

Note: A NIST calibration certificate may be used to fulfill this requirement, but other formats containing similar information are acceptable.

19.3: Is the calibration uncertainty shown in 19.2 consistent with stated calibration capabilities of the laboratory in other laboratory book sections?

Note: If the laboratory has a stated calibration accuracy less than the accuracy shown in this nominal measurement, those capabilities must be changed to match those obtained in the Section 19.2 measurements.

19.4: Are the results of the uncertainty analysis for primary calibration reflected in the day-to-day measure of calibration quality discussed in Section 10? In other words, are typical uncertainties used as a quality check for daily calibration measurements?

19.5: Does the laboratory have a "Report of Measurement" for its most commonly used calibration artifact stating its expected uncertainty under nominal operating conditions?

On-site Review: Ask the radar technicians to show (in tabular or graphical form) the predicted uncertainty of the primary calibration standard. Can the technicians find the information?
On-site Review: Do the technicians use the primary calibration target uncertainty bars to bracket acceptable (daily) calibration as a quality check?
On-site Review: Ask the following question and assess answer: Are the actions taken by the technicians when calibration measurements fall outside expectations consistent with the stated laboratory policy on exceptions to approved calibration process? (See Section 5 and Section 10.)

2.3.2 Priority 2 Sections

SECTION 5 - QUALITY SYSTEM, AUDIT, AND REVIEW (PRIORITY 2)
The purpose of this section is to ensure that a complete overview of the laboratory quality system and self-auditing process is provided. This section should contain the following:

- Procedures for the control and maintenance of documentation,
- Arrangements for ensuring that the laboratory reviews all new work to ensure that it has the appropriate facilities and resources before commencing such work,
- Management arrangements for permitting departures from documented policies and procedures or from standard specifications,
- Procedures for protecting confidentiality and proprietary rights, procedures for audit and review,

- Procedures for a management quality audit at least once a year,
- Procedures for documentation of all audit processes, and
- Procedures for tracking and monitoring the quality of the primary optical properties calibration data.

The Optical Properties Certification Review Committee Certification Report should be attached here upon completion of the certification review process.

Note 1: All items of Section 5 need to be addressed at some point in the laboratory book. Because of their importance, some of these items are treated in separate sections of the laboratory book. Any such information requested in Section 5, but appearing elsewhere in the laboratory book must be appropriately documented. For example, Section 5.2(a) appears in this book in Section 1. Here we include all items that are not treated separately, as listed after the section heading. The purpose of this section is to ensure that a complete overview of the company's quality system and its self-auditing process are given. Important miscellaneous items are to be included here. We recommend closely following the appropriate parts of Section 5 of the main text. Section 5.2(s) should be the section where the certification audit report is attached.

Note 2:

Z540 5.2e	is found in Laboratory Book	Section 6
Z540 Section 5.2f	is found in Laboratory Book	Section 1
APPENDIX I – Z540 Section 5.2g	is found in Laboratory Book	Section 9
Z540 Sections 5.2h, j, l, m, and n	are found in Laboratory Book	Section 10
Z540 Section 5.2k	is found in Laboratory Book	Section 11
Z540 Section 5.2q	is found in Laboratory Book	Section 16
Z540 Section 5.2r	is found in Laboratory Book	Section 4
Z540 Section 5.2u	is found in Laboratory Book	Section 19

Note 3: The numbering/lettering sequence below follows Z540.

<u>Evaluation Criteria</u>:

5.2a: Does the laboratory book contain a top management quality statement here or in Section 1?

5.2b: Are appropriate organizational charts in place here or in Section 4?

5.2c: Are the roles and responsibilities of management, technical operations, support services, and quality systems identified here or in Section 4?

5.2d: Does the laboratory book describe how documents are controlled and referenced?

5.2i: Does the laboratory organization have a process to assess whether it has the technical capability and resources (schedule time) to accept new work?

5.2o: Is there a clearly established policy and process when measurement discrepancies are seen or departures from documented policies and procedures occur?

5.2p: Is there a management policy for permitted departures from documented policies?

5.2s: Are periodic review processes documented?

Note: The Optical Properties Certification Review Committee Certification Report should be attached here upon completion of the review process.

5.2-t: Is the laboratory's policy for establishing and changing calibration intervals documented for systems or equipment it controls?

5.3: Are the laboratory's internal (annual) and external (every three year) audit processes documented? Have previous audit deficiencies been corrected by the next annual audit?

5.4: Was a management quality audit performed within the previous 12 months?

5.5: Are previous audits and their findings a permanent part of the laboratory book?

5.6: Does the laboratory have a process for tracking and monitoring the quality of the primary optical properties calibration data for calibration artifacts used in the normal measurement process?

Is there a day-to-day pass/fail check criteria established for calibration measurements?

Have the results been verified, either through repeated measurements, inter-laboratory comparisons or both?

On-site Review: Ask laboratory technicians what is the pass/fail criteria for calibration.

On-site Review: Ask laboratory technicians what is done if calibrations depart from expectations.

On-site Review: Review internal laboratory process of assessing new work (or a new customer requirement). Is it complete? Can it easily be provided to a customer on request?

SECTION 8 – EQUIPMENT AND REFERENCE MATERIALS (PRIORITY 2)
Configuration control is essential for maintaining a repeatable, quality optical properties system. Therefore, this section of the laboratory book may be one of the most significant. Here the laboratory should identify all applicable electro-optical equipment that makes up the optical properties laboratory. References to appropriate equipment manuals should be given in sufficient detail so that a qualified technician can trace the major subsystems of the laboratory. Maintenance and calibration histories should be kept for critical components, and complete system configuration should be tracked. The procedures for identifying equipment, maintenance, and configuration control should be documented here. Personnel responsible for following these procedures should be clearly identified. For electronic (digital/intra-net) laboratory books, it is not essential to include an electronic version of critical laboratory equipment in this section. However, the titles and exact locations of externally referenced documents must be included in this section.

Note: The numbering/lettering sequence below follows Z540.

Evaluation Criteria:

8.1: Does the laboratory have a list, database, or other log or configuration control method for identifying and tracking the main laboratory equipment systems and subsystems?

8.2a: For any laboratory equipment identified in 8.1, is a maintenance schedule identified for periodic or preventive maintenance?

8.2b: Is there any evidence the equipment maintenance schedules are being followed (i.e., last "check-on" date, maintenance logs, etc.)?

8.2c: For major laboratory systems or subsystems, are maintenance procedures clearly identified in either a reference manual or a printable procedure?

Reference manuals may be included in Section 10; cross-references here would be useful.

8.3a: Is any individual equipment in the laboratory system identified as to whether its internal calibration status affects the level of laboratory optical properties calibrations? (This requirement is N/A if end-to-end system calibration is performed as a routine practice at the laboratory.)

8.3b: For any equipment identified in 8.3-a, is the calibration status and interval of said equipment marked or displayed on the equipment? (If 8.3a is N/A, this section is N/A.)

8.4a: Is there an appropriate reference manual for each piece of laboratory equipment identified in 8.1? This requirement may be satisfied with a database or listing cross-referencing the equipment with its manual and its exact physical location when not in use.

8.4b: Does the document and equipment log show the name and current location of the equipment?

8.4c: Does the document(s) show the maintenance history of these pieces of equipment?

8.4d: Does the document show a history of damage, malfunction, modification, or repair of the items?

8.4e: If automated testing is used to verify subsystem performance (e.g., loop test modes, automated power supply monitoring, etc.), are non-compliant loop tests documented and corrected (or noted) prior to system use?

On-site Review: Select, at random, five pieces of equipment from the log of 8.1 above. Can the pieces of equipment be located?

On-site Review: Ask to see the maintenance procedures (if applicable) for those pieces of equipment. Are the manuals current?

On-site Review: Ask to see the reference manuals for the five pieces of equipment selected. Are the manuals readily available? Were those manuals found in the locations stipulated in the laboratory book?

On-site Review: For the five pieces of equipment selected, is there a historical log kept on damage, repair, or recalibration (if appropriate)?

SECTION 13 – CERTIFICATES AND REPORTS (PRIORITY 2)

This section should define the standard reporting formats used by the laboratories when reporting optical properties measurements to customers. While any report can be specialized to the requirements of the customer, this section should provide the baseline information that will always be available in a test report. A laboratory is allowed to use its own format if the minimum information required by ANSI Z540-1 is included.

Evaluation Criteria:

13.1: Does the laboratory book include a description of and purpose for each type of certificate or report employed or delivered by the laboratory (e.g., measurement data and test summary reports)?

13.2a: Does each certificate or report include:

- A title (e.g., Measurement Report)?
- Name and address of the facility?
- Points of contacts?
- Phone/fax numbers?
- Location(s) of the test(s)?
- Name, address, and points of contact of the customer?
- Description and unambiguous identification of the measured item (including its configuration, as appropriate)?
- Characterization and condition of the measured item?
- Date(s) and times(s) of the measurement(s)?
- Identification of the calibration procedure(s) used or unambiguous description of non-standard procedures employed; reference to sampling and/or data processing procedures, where relevant?
- Any deviations from, additions to, or exclusions from documented operating procedures?
- Other information relevant to the measurement(s) such as environmental conditions or failures/anomalies encountered during the measurement(s)?

13.2b: Does each certificate or report include measurements, examinations, and derived results supported by tables, graphs, sketches, and photographs (and/or digital representations of such), as appropriate for the measurements conducted?

13.2c: Does each certificate or report include a statement of the estimated uncertainty of the primary calibration results and the traceability of the measurements?

13.2d: Does each certificate or report include a signature and title of the person(s) accepting responsibility for the content of the certificate or report, and the date of issuance?

13.2e: Does each certificate or report include a statement regarding any limitations on the use or interpretation of the measurement data?

13.3: Are portions of the measurement data products performed by subcontractors? If so, are such portions clearly identified? (This will probably be N/A for most laboratories.)

13.4: Is there a procedure for amending a report? Is there a procedure for notifying customers promptly, in writing, of any event such as discovery of defective calibration equipment that may

cast doubt on the validity of the results provided in any given report or certificate, including the magnitude of the errors that may exist?
13.6: Is there a documented procedure for transmitting reports or certificates to customers or third party recipients such that confidentiality is preserved?

Note: A hand receipt, computer receipt, registered mail receipt, or other appropriate tracking system may be used to fulfill this requirement.

On-site Review: No on-site review criteria for this section.

SECTION 20 – ONGOING RESEARCH, PLANNED IMPROVEMENTS (PRIORITY 2)
The purpose of this section is to briefly summarize the three-year look ahead regarding any laboratory research and/or other activities designed to improve laboratory data quality, efficiency, repeatability, or traceability. A list of desirable research areas to be conducted in the future to improve specific and known deficiencies on the laboratory or in the optical properties industry should also be provided, as well as a single top-level roadmap. Ongoing plans for future upgrades of equipment should be included. Such research information will allow customers to quickly identify and evaluate ongoing laboratory improvements in the context of their current or planned use of the laboratory. It also may offer the customer an opportunity to cost share or jointly sponsor laboratory research of interest to the customer.

Evaluation Criteria:

20-1: Is there a description or summary of future planning such as three-year plans, upgrades, and quality or laboratory improvements?

20-2: Is there a roadmap formatted to summarize the three-year plan?

Note: The roadmaps may be longer than three years but must, at a minimum, look ahead three years.

On-site Review: As a result of the review committee feedback, is there a summary of topics and issues that will be worked on a time-available basis over the succeeding three years?

2.3.3 Priority 3 Sections

SECTION 1 – INTRODUCTION AND ENDORSEMENT (PRIORITY 3)

This section should contain a brief statement of compliance with the standards set by this document in accordance with ANSI/NCSL Z-540-1-1994, as well as a clear policy statement regarding the organization's commitment to continuous quality improvement. The laboratory book should be signed as “approved” by an appropriate manager or director at or near the top of the reporting chain of the laboratory quality manager or technical lead engineer. The exact format and wording may be customized to suit the organization.

Evaluation Criteria:
1.1: Does the laboratory book identify the host organization?

1.2: Is the endorsement signed by an appropriate manager or director who has the responsibility and authority to direct changes and corrections if laboratory or product deficiencies are found? (Alternate location for Section 5.2f.)

1.3: Is there a clear commitment to quality in the introduction and endorsement?

On-site Review: Ask to meet the endorser. Is the endorser clearly committed to the quality process?

SECTION 2 - REFERENCES (PRIORITY 3)
This section should list the documents cited in the laboratory book. In particular, it may be convenient to include stand-alone reports covering various aspects of laboratory operations (operational security, measurement procedures, uncertainty analysis procedures, equipment documentation, etc.), which could be included in the laboratory book by reference only.

Evaluation Criteria:
2.1: Does the laboratory book include a list of documents and references external to the laboratory book?

2.2: Are all references unambiguous enough to identify the documents?

2.3: Are the documents listed cross-referenced or linked to the appropriate laboratory book section?

References maybe hyper-linked to the actual document, or if the document is not digital or otherwise not available via electronic/digital connection, then the location must be identified.

On-site Review: Ask to see five documents at random on the list.

SECTION 3 – GLOSSARY (PRIORITY 3)
This section should list and define the specialized terms and acronyms used in the laboratory book. All acronyms should be defined upon first use. Specialized terms related to the acquisition and processing of optical properties data should also be defined. The information in this section should aid the reviewers in translating technical jargon from the body of the report.

Evaluation Criteria:
3.1: Does the laboratory book contain an appropriate glossary?

3.2: Do acronyms (jargon) occur in any laboratory book section that are not defined (immediately) in that section or listed here in the glossary?

On-site Review: No on-site review criteria for this section.
Note: Reviewers: Please list any undefined acronyms below.

_____

_____

_____

Note: Laboratory Book Authors: After review, please include in the glossary any acronyms or terms identified by reviewers as undefined.

SECTION 4 – ORGANIZATION AND MANAGEMENT STRUCTURE (PRIORITY 3)
This section should fully define the organization that is chartered to operate the laboratory. The management hierarchy from the laboratory line technicians and engineers up through the highest levels of laboratory management should be defined. Lead personnel and approved signatories should be identified. The laboratory quality manager and technical managers *must be identified*. Ideally, work phone numbers should be available for all critical laboratory personnel. Standard company organization charts are acceptable. In addition, a policy statement on customer confidentiality and or proprietary rights protection must be included here.

Evaluation Criteria:
4.1: Does the laboratory book contain a complete reporting chain or organizational chart of the laboratory?

4.2: Does the laboratory identify a laboratory technical manager?

4.3: Does the laboratory identify the laboratory quality manager?

4.4: Does the laboratory identify the management chain from the technician level to the highest level of the organization?

4.5: Does the laboratory quality manager have direct and unfettered access to the individual signing the endorsement in Section 1, Introduction and Endorsement?

4.6: Is there a clear policy on non-disclosure and/or company proprietary data or information?

4.7: If laboratory operators, engineers, and/or technicians are from a different organization or company than the laboratory owners, are the respective roles and responsibilities of the two organizations and their interfaces clearly spelled out?

4.8: Are personnel qualifications available or referenced in other laboratory book sections?

4.9: In cases of absence, are alternate technical and quality managers identified?

On-site Review: Ask laboratory technicians to identify the technical and quality managers.
On-site Review: Ask the quality manager if he/she has direct access to the endorser of Section 1.
On-site Review: Check to see whether the laboratory technicians and engineers know who the primary and alternate technical and quality managers are.
On-site Review: Is the laboratory supervision done by person(s) familiar with the calibration methods and procedures, the objective of the calibration, and how to assess the results?

SECTION 6 - PERSONNEL (PRIORITY 3)
This section should contain the qualifications of all personnel assigned to the laboratory. Specialized training, training certificates, or other laboratory-related qualifications should appear in this section. Company or resume format may be used. If an organization, due to personnel policy or union concerns, treats their records as "company sensitive" or "company confidential," the laboratory book should so state, and indicate what individual and organization has these records, and who has the right to review and update them. It is the responsibility of the laboratory to certify that their staff has the qualifications to do their jobs. Updated training

records are one indicator of the currency of training. If the reviewers are not allowed to see these records, the laboratory technical manager may certify, in a signed statement herein, that such records exist in a remote location, and that these records demonstrate that the employees meet the minimum qualification standards for their respective jobs. Note that any training program should not only address day-to-day competencies, but also allow for technical growth to build expertise to support future tasks, like those identified in Section 20.

Evaluation Criteria:

6.1: Does the laboratory employ an appropriate mix of technician, engineering, and management personnel with appropriate experience to perform their assigned functions? (Alternate location for 5.2-e)

Note of caution: Are the personnel qualifications written to match the available workforce, or do they truly represent the skill sets needed to perform the work in a competent manner?

6.2: Does the laboratory have a formal training program, and if so, are records kept up to date? Is the training offered sufficient to ensure or maintain technical competence?

6.3: Are the training records available to laboratory management?

Note: These records do not have to reside in the laboratory book but must be identified by location.

On-site Review: Ask to locate the personnel training records of 6.3.

SECTION 7 – ACCOMMODATION AND ENVIRONMENT (PRIORITY 3)

This section should document the laboratory environment as well as any and all parameters of the laboratory environment that may affect the outcome of measurements and thereby should be monitored. Some environmental variables that could affect optical measurements include electromagnetic interference, temperature variations, and mechanical vibrations, etc. (Depending on the complexity of the laboratory, this section may or may not be significant.)

Evaluation Criteria:

7.1: (Deleted) Same criteria is found in Section 10-7d.

7.2: Are the nominal measurement environmental factors specified for acceptable operations (e.g., allowable temperature variations, etc.)?

7.3: Are appropriate environmental parameters recorded as a part of the test process?

On-site Review: Are the environmental factors identified being recorded in a log or with the data? For environmental measurements being recorded, review such data and operations with laboratory technicians.

On-site Review: Is there any measurement data showing system stability or repeatability versus stated control values for environmental variations? (In other words, are the factors in 7.2 derived based on data and if so, what data?)

SECTION 12 – RECORD KEEPING (PRIORITY 3)

This section describes the laboratory's procedures for creating and maintaining records of all aspects of laboratory operations. Procedures for maintaining calibration records, measurement records, system configuration, etc., are especially important.

Evaluation Criteria:
12.1: Does the laboratory have well-documented procedures for creating and maintaining records of laboratory operations, to include records of calibration, measurements, and system configuration?

12.2: Are these records indexed or stored so they are easily located and accessible to those with a need to review them?

On-site Review: No on-site review criteria for this section.
Note: This section may be evaluated in conjunction with the examination of the records required by other sections, such as 13, 14, 15, 16, 17, etc.

SECTION 14 – SUBCONTRACTING RECORDS (PRIORITY 3)
This section details any aspects of the optical properties calibration process that are subcontracted. Any subcontracted work must satisfy the ANSI Z540-1 standard. (This section may not be applicable for most laboratories.) The main intent of this section is to address calibration activities sent to locations or personnel that are not within the laboratory facility (on-site). When on-site contractors share complete responsibility for operating a laboratory facility, as is often the case, we refer to this situation as an integrated product team. For example, AFRL hires an on-site contractor to assist in laboratory operations. This is not considered subcontracting. However, if a primary laboratory relies on an off-site secondary optical properties laboratory for calibration data or other measurements applicable to the primary laboratory, this situation would be treated as a subcontracted measurement, and Section 14 would apply. For most laboratories, these criteria probably will not apply.

Evaluation Criteria:
14.1: If the laboratory employs any subcontracting in the performance of optical properties measurements, is there a documented procedure or policy that stipulates and verifies that such. Does the laboratory maintain records of the work accomplished by subcontractors?

14.2: If the laboratory employs a contractor to perform measurements, does the contract or other operational document bind the contractor to the procedures defined by the laboratory book?

On-site Review: Ask the laboratory manager whether subcontractors/contractors support or perform optical properties measurements. If applicable, review the contract(s) to verify compliance with the ANSI-Z540 requirements.

SECTION 15 – OUTSIDE SUPPORT SERVICES AND SUPPLIERS (PRIORITY 3)
This section should document any services or suppliers used to produce calibrated optical properties data. This section complements Section 14. For instance, if a laboratory purchases a reflectance standard from a vendor for primary calibration, this section would document the needed tolerances of such a standard, as well as the delivered tolerance of the calibration item.

Evaluation Criteria:
15.1: Are there documented policies that ensure the quality of the calibrations and measurement products if the laboratory uses outside services or suppliers that might adversely affect the quality and accuracy of optical properties measurements.

15.2: Does the laboratory book identify outside services or suppliers, or is there a definitive statement that no outside suppliers or services are employed in the calibration and measurement functions of the laboratory?

15.3: Where applicable, are there procedures for maintaining records associated with outside services or suppliers?

On-site Review: If outside suppliers or services are used at the laboratory under review, ask to see the associated records.

SECTION 16 – COMPLAINTS (PRIORITY 3)
This section should document the formal complaint procedure used to resolve disputes between the laboratory and a customer. The complaint record keeping system also should be defined or referenced here.

Evaluation Criteria:
16.1: Does the laboratory have documented procedures for the resolution of customer complaints?

16.2: Are records maintained of all complaints and of the actions taken by the laboratory to resolve the complaints?

16.3: If a customer complaint raises a concern regarding the laboratory's compliance with laboratory policies or procedures, or with the requirements of this standard, does the laboratory have procedures to ensure that these complaints are reviewed and acted upon by a level of authority at least as high as the signatory identified in Section 1? Is this individual able to effect the required changes in laboratory policy and procedures, if needed?

16.4: If the customer complaint raises a concern regarding the quality of the laboratory's calibrations, does the laboratory ensure that these complaints are reviewed and acted upon by a level of authority at least as high as the signatory identified in Section 1? Is this individual able to effect the required changes in laboratory policy and procedures, if needed?

On-site Review: Examine records of a random complaint (if applicable) to ensure that the complaints were reviewed and that appropriate action was taken and recorded.
On-site Review: Ask laboratory personnel if they are familiar with the laboratory's complaint resolution process.
On-site Review: Ask the laboratory quality manager if and how he/she is involved in the complaint resolution process. Does the laboratory quality manager review all customer complaints for indications that current policies and procedures are in need of review?

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CHAPTER 3

MODIFIED ANSI Z-540.1-1994-BASED EVALUATION CRITERIA FOR USE BY EO/IR FACILITIES

3.1 Criteria Modifications Based on Lessons Learned

The following evaluation criteria were derived from the ANSI Z-540.1-1994-based evaluation criteria presented in Chapter 2, modified by the evaluators subsequent to their application of the criteria in Chapter 2. The criteria presented here were modified based on lessons learned during the three evaluations of the OMF *Lab Book*, with the modifications seeking to reduce ambiguity, delete redundancies, and improve clarity.

The recommendation of the participants is that evaluation criteria based on either ANSI/NCSL Z540.3-2006 or the ISO-17025 be adopted by the RCC/SMSG for the EO/IR laboratory community. Alternatively, and as a minimum, evaluation criteria based on ANSI Z540.1-1994 (R2002), as presented in Chapter 2 , could be used, but because of the breadth and diversity of facilities/organizations that might follow this program, the more contemporary standards would likely be more palatable. The criteria below reflect modifications made by the evaluators after the three evaluations. The modifications were made to delete ambiguous, duplicative, or irrelevant requirements, and improve clarity and readability.

The recommendation of the participants is that the evaluation criteria in Chapter 2 be reviewed and additional testing of those criteria by multiple facilities occurs before finalizing the criteria. A multi-facility test of the process and criteria would follow the same path as the RCS certification program, in which three very different facilities were employed to test the process and criteria. Once more broadly tested criteria have been refined, those criteria should be presented to the EO/IR community, writ large, along with the background as to how those criteria were evolved, so that broad consensus can be reached.

Compliance with the evaluation criteria presented below does not imply compliance with ANSI Z-540 or any other quality standard, although the intent is to satisfy the basic requirements for a quality measurement program.

3.2 Construct of the Code

The construct/format of the modified code is shown in Table 3-1. Table 3-2 shows the modified Z-540-1994-1-based evaluation criteria for EO/IR Measurement Facilities/Organizations (MFOs), and follows the construct in Table 3-1.

TABLE 3-1. CONSTRUCT OF THE CODE

sXX	nXXX	pX	pnXX
Section number (from the unmodified criteria)	Criteria number, starting with n001 as the first criteria in Section 1 and going to n115 for the last criteria in Section 21	Priority level (where p1 is the highest priority and p3 is the lowest priority (See Chapter 2)	Priority number within the associated Section (sXX)

In Table 3-2, the number in the criteria column (e.g., *9.1: Does the laboratory…)* is the criteria number from the original Z-540-based criteria presented in Chapter 2?

TABLE 3-2. MODIFIED Z-540-1994-1-BASED EVALUATION CRITERIA FOR EO/IR MEASUREMENT FACILITIES/ORGANIZATIONS

Code Construct	Criteria
s09-n043-p1-pn01	9.1: Does the laboratory have an established and documented program to ensure its calibration program supports the stated calibration performance of its measurement system(s)?
s09-n044-p1-pn02	9.2: Is the laboratory calibration process traceable to a published (AMTA, IEEE, etc.) calibration item standard or other national standard (when developed)?
s09-n045-p1-pn03	9.3: Does the laboratory measurement and calibration program include a schedule for calibration intervals for each piece of test equipment used to assess system performance?
s09-n046-p1-pn04	9.4: Is there documentary evidence the schedule (9.3) is being followed?
s09-n047-p1-pn05	9.6: Does the laboratory have a documented program to monitor test equipment and/or calibration items between scheduled calibrations and verifications?
s09-n048-p1-pn06	9.7: When the laboratory participates in inter-laboratory comparisons (See 5.6), is the laboratory's system configuration employed in those comparisons clearly documented?
s09-n049-p1-pn07	On-site Review: For the primary calibration items, are samples of "acceptable" calibrations or verification records available?
s10-n050-p1-pn08	10.1-a: Does the laboratory have documented system-wide calibration procedures?
s10-n051-p1-pn09	10.2-a: Are separate calibration and measurement procedures for each major measurement system or for each type of measurement conducted available?

Code Construct	Criteria
s10-n052-p1-pn10	10.2-b: Are the calibration measurement procedures consistent with the accuracy required for each type of calibration measurement (as defined in the uncertainty analysis in Section 19)?
s10-n053-p1-pn11	10.3: Are the procedures for deriving or assigning values for a measured target through the use of transfer standards documented?
s10-n054-p1-pn12	10.4: Are system-wide calibrations scheduled on an appropriate cycle for the measurement system? Is this cycle defined? Is there evidence they are being performed when scheduled? Are the results of system-wide calibrations included or referenced in this section? Are these calibrations provided to the customer as part of their normal data report?
s10-n055-p1-pn13	10.5: If sampling is included as a part of calibration or measurements, is documentation available that describes the procedures and applied statistical techniques employed (detailed data processing implementations may be provided/discussed in Section 18, if applicable)?
s10-n056-p1-pn14	10.6: Do the results of acceptable system-wide calibrations support the uncertainty bounds established in Section 19?
s10-n057-p1-pn15	10.7-a: For computer software used to acquire and/or store the raw data, are user manual(s) available either as automated help files, or as separate document(s), which describe the correct operation and use of this software? If the manual is not available on-line, is the physical location of the documentation clearly identified?
s10-n058-p1-pn16	10.7-b2 Is there a database or other appropriate tracking list of the computer program(s) that are used in the end-to-end data acquisition, transmission, and processing steps?
s10-n059-p1-pn17	10.7-b3 For computer software used to process the raw data files into final data products, are appropriate user's manual and/or help files available?
s10-n060-p1-pn18	10.7-c1 Is an assigned computer support and/or network administrator available to maintain computer equipment used in the laboratory data acquisition and processing?
s10-n061-p1-pn19	10.7-c2 Is there a diagram of the local area network within the laboratory, if applicable?
s10-n062-p1-pn20	10.7-d: Are computers used to monitor critical environmental and/or operating procedures in order to maintain the stated calibration accuracy and/or stay within the published calibration uncertainty of Section 19? If so, are the operators alerted if the conditions are unacceptable?
s10-n063-p1-pn21	10.7-e: Are there procedures that ensure security of the data to prevent the unauthorized or inadvertent access, manipulation, or destruction of computer data or records? (Note that an approved network AIS or SPP plan will satisfy this requirement. If the AIS/SPP is not electronically available in the laboratory book, its physical location must be precisely identified.)

Code Construct	Criteria
s10-n064-p1-pn22	On-site Review: Request the laboratory manager perform a system-wide calibration. Verify the documented procedures are followed by laboratory technicians.
s10-n065-p1-pn23	On-site Review: Compare the results of the system-wide calibration with the historical records found in Sections 12, 13 and/or 19. Are the results within the stated calibration uncertainty limits?
s10-n066-p1-pn24	On-site Review: Ask a technician if the observed documented procedures are up to date. Ask when the procedures were last reviewed for completeness and accuracy.
s11-n067-p1-pn25	11.1: Does the laboratory have a system for uniquely identifying primary calibration items?
s11-n068-p1-pn26	11.2: Does the laboratory have a system for assessing the calibration items upon initial receipt? Are visual inspection(s) performed on the calibration items as part of the calibration process? Is there a stated procedure for reacting to items that are out of tolerance?
s11-n069-p1-pn27	11.3: Does the laboratory have documented procedures and appropriate facilities to avoid deterioration or damage to calibration items during storage, handling, preparation, and calibration?
s11-n070-p1-pn28	11.4 Is the exact location of the calibration item standard identified when not in use?
s11-n071-p1-pn29	11.6: If the primary calibration items employed by the laboratory are used in any capacity other than to ensure the performance of the measurement system(s) do such uses damage the calibration items?
s11-n072-p1-pn30	On-site Review: Perform a visual inspection of the laboratory's calibration items to determine the conditions, procedures, and facilities assessed in 11.1 through 11.6 are as stated.
s18-n098-p1-pn31	18.1: Does the laboratory have all data processing procedures documented?
s18-n099-p1-pn32	18.2: Have the data processing modules been validated with a standard data set to ensure the correctness of the algorithms employed?
s18-n100-p1-pn33	18.3: Are the results of data processing compared against known quantities or standards to verify accuracy of the measurement and data processing process?
s18-n101-p1-pn34	On-site Review: Is there a procedure to collect, determine and validate all customer data processing requirements, to include such key items as specific formats, parameters and quantities? Is there a procedure for translating user requirements into the specific procedures to collect the data identified by the customer?
s18-n102-p1-pn35	On-site Review: Are procedures in place to coordinate target readiness and state with data collectors and data processors so that the target configuration is captured throughout the data collection and processing chain?

Code Construct	Criteria
s18-n103-p1-pn36	On-site Review: Are procedures in place for validating the data in (near) real-time to ensure the proper data is being collected?
s18-n104-p1-pn37	On-site Review: Ask a laboratory technician to process a file from a standard data set and compare the results to those known to be correct.
s18-n105-p1-pn38	On-site Review: Ask the laboratory technical manager how new or improved data processing algorithms are validated.
s18-n106-p1-pn39	On-site Review: Review the results of any inter-laboratory data processing comparisons. Are these results available to laboratory customers?
s19-n107-p1-pn40	19.1 Does the laboratory have a policy for the development and use of a calibration uncertainty analysis? (Alternate location for section 5.2-u.)
s19-n108-p1-pn41	19.2 For the primary calibration standard(s) used by the laboratory, is there a nominal measurement with estimated uncertainties, in either graphical or tabular form for that standard?
s19-n109-p1-pn42	19.3 Is the calibration uncertainty shown in 19.2 consistent with stated calibration capabilities of the laboratory in other Laboratory Book sections? (Note: If the laboratory's stated calibration accuracy is less than the accuracy shown in this nominal measurement, those capabilities must be changed to match those obtained in the section 19.2 measurements.)
s19-n110-p1-pn43	19.4 Are the results of the uncertainty analysis for primary calibration reflected in the day-to-day measure of calibration quality discussed in Section 10? (Note: In other words, are typical uncertainties used as a quality check for daily calibration measurements?)
s19-n111-p1-pn44	On-site Review: Ask the technicians to show (in tabular or graphical form) the predicted uncertainty of the primary calibration standard. Can the technicians find the information?
s19-n112-p1-pn45	On-site Review: Do the technicians use the primary calibration target uncertainty bars to bracket acceptable (daily) calibration as a quality check?
s19-n113-p1-pn46	On-site Review: Are the actions taken by the technicians when calibration measurements fall outside expectations consistent with the stated laboratory policy on exceptions to approved calibration process (See Sections 5 and 10)?
s05-n015-p2-pn01	5.2-a: Is there a management quality statement here or in Section 1?
s05-n016-p2-pn02	5.2-c: Are the roles and responsibilities of management, technical operations, support services, and quality systems identified here or in Section 4?
s05-n017-p2-pn03	5.2-d: Is there a description of how documents are controlled and referenced?

Code Construct	Criteria
s05-n018-p2-pn04	5.2-i: Does the laboratory have a process to assess whether it has the technical capabilities and resources (including schedule time and consumables) before scheduling new work?
s05-n019-p2-pn05	5.2-o: Is there a clearly established policy and process when measurement discrepancies are seen or departures from documented policies and procedures occur?
s05-n020-p2-pn06	5.2-t: Is the policy for establishing and changing calibration intervals documented?
s05-n021-p2-pn07	5.3: Are the laboratory's internal and external audit processes documented (including reviewers names, date audit started/completed, complete report, and final scores)? Have previous audit deficiencies been corrected by the next annual audit?
s05-n022-p2-pn08	5.4: Was a management quality audit performed within the previous 12 months?
s05-n023-p2-pn09	5.6: Does the laboratory have a process for tracking and monitoring the quality of the primary calibration data for calibration items used in the normal measurement process? Is there a day-to day pass/fail check criteria established for calibration measurements? Have the results been verified, either through repeated measurements, inter-laboratory comparisons or both?
s05-n024-p2-pn10	On-site Review: Ask laboratory technicians what the pass/fail criteria for calibration are.
s05-n025-p2-pn11	On-site Review: Ask laboratory technicians what is done if calibrations depart expectations.
s08-n035-p2-pn12	8.1: Does the laboratory have a list, database, or other log or configuration control method for identifying and tracking the main laboratory equipment systems and subsystems? Are there omissions?
s08-n036-p2-pn13	8.2-a: For laboratory equipment identified in 8.1, is a maintenance schedule identified for periodic or preventative maintenance?
s08-n037-p2-pn14	8.2-b: Is there any evidence the equipment maintenance schedules are being followed (i.e., last .check-on. date, maintenance logs, etc.)?
s08-n038-p2-pn15	8.2-c: For major laboratory systems or subsystems, are maintenance procedures clearly identified?
s08-n039-p2-pn16	On-site Review: Select, at random, five pieces of equipment from the log of 8.1 above. Can the pieces of equipment be located?
s08-n040-p2-pn17	On-site Review: Ask to see the maintenance procedures (if applicable) for those pieces of equipment. Are they up to date?
s08-n041-p2-pn18	On-site Review: Ask to see the reference manuals for the five pieces of equipment selected. Are the manuals readily available? Were those manuals found in the locations stipulated in the Laboratory Book?

Code Construct	Criteria
s08-n042-p2-pn19	On-site Review: For the five pieces of equipment selected, is there a historical log kept on damage, repair, or re-calibration (if appropriate)?
s13-n075-p2-pn20	13.1: Is there a description and purpose for each type of certificate or report employed or delivered by the laboratory (e.g., measurement data and test summary reports)?
s13-n076-p2-pn21	13.2-a: Does each certificate or report include: a title (e.g., Measurement Report); name and address of the facility, points of contacts, phone/fax numbers and location(s) of the test(s); name, address and points of contact of the customer; description and unambiguous identification of the measured item (including its configuration, as appropriate); characterization and condition of the measured item; date(s) and times(s) of the measurement(s); identification of the calibration procedure(s) used or unambiguous description of non-standard procedures employed; reference to sampling and/or data processing procedures, where relevant; any deviations from, additions to or exclusions from documented operating procedures, and other information relevant to the measurement(s), such as environmental conditions or failures/anomalies encountered during the measurement(s)?
s13-n077-p2-pn22	13.2-b: Does each certificate or report include measurements, examinations and derived results, supported by tables, graphs, sketches and photographs (and/or digital representations of such), as appropriate for the measurements conducted?
s13-n078-p2-pn23	13.2-c: Does each certificate or report include a statement of the estimated uncertainty of the primary calibration results and the traceability of the measurements?
s13-n079-p2-pn24	13.2-d: Does each certificate or report include a signature and title of the person(s) accepting responsibility for the content of the certificate or report, and the date of issuance?
s13-n080-p2-pn25	13.2-e: Does each certificate or report include a statement regarding any limitations on the use or interpretation of the measurement data?
s13-n081-p2-pn26	13.3: Are portions of the measurement data products performed by sub-contractors? If so, are such portions clearly identified?
s13-n082-p2-pn27	13.4: Is there a procedure for amending a report? Is there a procedure for notifying customers promptly, in writing, of any event such as discovery of defective calibration equipment that may cast doubt on the validity of the results provided in any given report or certificate, including the magnitude of the errors that may exist?
s13-n083-p2-pn28	13.6: Is there a documented procedure for transmitting reports or certificates to customers or third party recipients such that confidentiality is preserved? Note: a hand receipt, computer receipt, registered mail receipt, or other appropriate tracking system may be used to fulfill this requirement.

Code Construct	Criteria
s17-n094-p2-pn29	17.1: Does the laboratory have a documented policy on inter-laboratory comparisons?
s17-n095-p2-pn30	17.2: Does the laboratory participate in an inter-laboratory calibration comparison program at the national level?
s17-n096-p2-pn31	17.3: Are the results of the inter-laboratory calibration comparisons of Section 17.2 available for customer review?
s17-n097-p2-pn32	17.4: Are the results of the inter-laboratory comparisons used to evaluate and improve the laboratory's operation?
s21-n114-p2-pn33	20-1: Is there a description or summary of a three-year look-ahead into future plans, upgrades, and quality or laboratory improvements?
s21-n115-p2-pn34	20-2: Is there a roadmap formatted to summarize the three-year plan. (Note that the roadmaps can be longer than 3 years, but must as a minimum look-ahead of 3 years).
s01-n001-p3-pn01	1.1: Is the host organization identified? Is the endorsement signed by a high-level manager or director? (Recommended to be at least two levels of management above the laboratory quality manager.)
s01-n002-p3-pn02	1.3: Is there a clear commitment to quality in the introduction and endorsement?
s01-n003-p3-pn03	On-site Review: Ask to meet the endorser. Is the endorser clearly committed to the quality process?
s02-n004-p3-pn04	2.2: Are all references unambiguous enough to identify documents?
s02-n005-p3-pn05	2.3: Are the documents cross-referenced or linked appropriately?
s02-n006-p3-pn06	On-site Review: Ask to see 5 documents at random in this list.
s03-n007-p3-pn07	3.1: Is there an appropriate glossary?
s03-n008-p3-pn08	3.2: Do acronyms (jargon) occur that are not defined (immediately) in that section or listed here?
s04-n009-p3-pn09	4.2: Does the laboratory identify a laboratory technical manager, a laboratory quality manager and alternates in case of absence?
s04-n010-p3-pn10	4.4: Does the laboratory identify the management chain from the technician level to the highest level of the organization?
s04-n011-p3-pn11	4.6: Is there a clear policy on non-disclosure and/or company proprietary data or information?
s04-n012-p3-pn12	4.7: If laboratory operators, engineers, and/or technicians are from a different organization or company than the laboratory owners, are the respective roles and responsibilities of the two organizations and their interfaces clearly spelled out?
s04-n013-p3-pn13	4.8: Are personnel qualifications available or referenced?
s04-n014-p3-pn14	On-site Review: Is the laboratory supervision done by person(s) familiar with the calibration methods and procedures, the objective of the calibration and how to assess the results?

Code Construct	Criteria
s06-n026-p3-pn15	6.1: Does the laboratory employ an appropriate mix of technician, engineering and management personnel with appropriate experience to perform their assigned functions? (Alternate location for 5.2-e)
s06-n027-p3-pn16	6.2: Does the laboratory have a formal training program and if so, are records kept up to date? Is the training offered sufficient to ensure or maintain technical competence?
s06-n028-p3-pn17	6.3: Are the training records available to laboratory management?
s06-n029-p3-pn18	On-site Review: Ask to locate the personnel training records of 6.3.
s07-n030-p3-pn19	7.1: Does the laboratory control and monitor critical or appropriate environmental parameters which may affect the proper performance and calibrations?
s07-n031-p3-pn20	7.2: Are the nominal measurement environmental factors specified for acceptable operations (e.g., allowable wind speeds, temperature variations, etc)?
s07-n032-p3-pn21	7.3: Are appropriate environmental parameters recorded as a part of the test process?
s07-n033-p3-pn22	On-site Review: Are the environmental factors identified being recorded in a log or with the data? For environmental measurements being recorded, review such data and operations with laboratory technicians.
s07-n034-p3-pn23	On-site Review: Is there any measurement data showing system stability or repeatability versus stated control values for environmental variations? (In other words, are the factors in 7.2 derived based on data and if so, what data?)
s12-n073-p3-pn24	12.1: Does the laboratory have well-documented procedures for creating and maintaining records of laboratory operations, to include records of calibration, measurements and system configuration?
s12-n074-p3-pn25	12.2: Are these records indexed or stored so they are easily located and accessible to those with a need to review them.
s14-n084-p3-pn26	14.1: If the laboratory employs any subcontracting in the performance of measurements, is there a documented procedure or policy that stipulates and verifies such subcontractors adhere to the provisions of an appropriate quality management system? Does the laboratory maintain records of the work accomplished by subcontractors?
s14-n085-p3-pn27	14.2: If the laboratory employs a contractor to perform measurements, does the contract or other operational document bind the contractor to the appropriate procedures?
s14-n086-p3-pn28	On-site Review: Ask the laboratory manager if subcontractors/contractors support or perform measurements. If applicable, review the contract(s) to verify flow-down of the quality system requirements.

Code Construct	Criteria
s15-n087-p3-pn29	15.1: If the laboratory uses outside services or suppliers which might impact the quality and accuracy of measurements, are there documented policies that ensure the level of quality of the laboratory's calibrations and measurement products?
s15-n088-p3-pn30	15.3: Where applicable, are there procedures for maintaining records associated with outside services or suppliers?
s15-n089-p3-pn31	On-site Review: If outside suppliers or services are used at the laboratory under review, ask to see the associated records.
s16-n090-p3-pn32	16.1: Does the laboratory have documented procedures for the resolution of customer complaints?
s16-n091-p3-pn33	16.2: Are records maintained of all complaints and of the actions taken by the laboratory to resolve the complaints?
s16-n092-p3-pn34	On-site Review: Examine records of a random complaint (if applicable) to ensure that the complaints were reviewed and that appropriate action was taken and recorded.
s16-n093-p3-pn35	On-site Review: Ask the laboratory quality manager if and how they are involved in the complaint resolution process. Does the laboratory quality manager review all customer complaints for indications that current policies and procedures are in need of review?

CHAPTER 4

SURVEY INSTRUCTIONS AND SURVEY FORM (NOV 2006)

4.1 Introduction

As part of the RCC effort to serve the technical and operational needs of member test ranges or facilities, the SMSG was formed to document signature measurement standards across the electromagnetic spectrum, and specifically in the following areas: radar, millimeter wave (MW), infrared (IR), laser, visible, ultraviolet (UV), seismic, acoustic, and magnetic. The unclassified survey was distributed as an initial effort to collect feedbacks from member EO/IR ranges or facilities for subjects and contents related to EO/IR measurements that should be included in the SMSG draft. The instructions used for the survey and the survey form are at paragraph 4.3 and paragraph 4.4, respectively.

4.2 Objective

The objectives of the survey were to:

a. Collect feedbacks on technical and operational needs among member EO/IR ranges;
b. Exchange ideas on common measurement procedures that can be standardized;
c. Learn common error or uncertainty analysis methodology and format currently used;
d. Find common interests in hardware or instrumentation to be included in the draft;
e. Find common documentation and data report format preferences
f. Elect candidate applications or measurements suitable for range demonstration

4.3 Specific Instructions used for the Survey

The survey is in MS Word 2003 format. It makes use of the Forms tools. In all cases, please check all that apply. The comment fields for the 'Other' boxes are of unlimited length and will wrap around if you need additional space. As there are drop down boxes, it is intend to be filled in electronically. If needed, the form can be printed out and the answers hand written. For the drop down boxes, please use the same answers as listed in the drop down box.

Please return completed survey by Dec 15 by one of the following:

Email: Jeffrey.Burks@wpafb.af.mil or Scott.Milster@atk.com
Fax: (937) 656-7074 (Jeff Burks) or (937) 431-1402 (Scott Milster)
Mail: Jeff Burks or Scott Milster
AFRL/SNS ATK Mission Research
2591 K St 3975 Research Blvd
WPAFB OH 45433 Dayton, OH 45430

For question 8, if you need additional subsections for different instruments it is easy to expand these. First, turn off the 'Protect Document' feature. Do this by going to the Tools menu and clicking on 'Protect Document', or if you have the 'Forms Toolbar' displayed click on the 'Protect Form' button which looks like a lock. There is no password set for the form. At this point, you can edit the document just like any Word document, so you can cut and paste as needed to expand the form.

Once you are done editing, start enforcing the protection by either clicking on the button 'Yes, Start Enforcing Protection' to the right, or clicking on the 'Protect Form' button on the 'Forms Toolbar'. Make sure the 'Editing Restrictions' allow 'Filling in Forms'. This is the initial setting so you should not have to change it. If the 'Password' box appears, just leave it blank and click Okay. This will allow you to tab through the form fields.

Note: The format is only there to make it easier for you to respond. Our main objective is the information, not the format! Electronic responses in English are preferred, but we will accept typewritten, faxed, handwritten, or any other way you choose to convey the information.

Thank you for your time. We plan to compile the responses and create a catalog in addition to the standard procedures. We need everyone's help to make it as comprehensive as possible. We look forward to your response.

Sincerely,

Jeff Burks
AFRL/SNS
937 255 9205

Scott Milster
ATK Mission Research
(937) 429 9261 extension 156

4.4 Survey Form

RCC/SMSG EO/IR SURVEY – NOVEMBER 2006

- Contact Information:
  Name: Organization/Range:
  Phone Number: FAX Number:
  E-Mail:

- What types of targets do you collect EO/IR information on?
  Coupons: Scale Models:
  Full size/actual targets:
  Other ( ):

- What type of tests do you conduct? Check all that apply.
  ☐ Static ☐ Wind Tunnel ☐ Free Flight ☐ Sled ☐ Wire guided
  ☐ Other _____
  ☐ Air to air:
  Sensor aircraft:
  Maximum altitude Maximum test duration
  ☐ Air to gnd ☐ Gnd to air ☐ Gnd to Gnd ☐ Air to ship

- What type of measurements do you collect of the target? Check all that apply.
  ☐ Radiometric ☐ Images ☐ Spectral ☐ Spectral Images ☐ Polarization
  ☐ Reflectance ☐ Transmittance ☐ BRDF ☐ DHR
  ☐ Temperature range**:**
  ☐ Thermocouple, type ☐ RTD, type
  ☐ Other: _____

- What types of calibration sources do you have? Check all that apply.
  ☐ Blackbody**:** Highest temp. , Lowest temp. , Size of largest BB
  ☐ Common Source ☐ Spectral lamps
  ☐ Other

- What type of calibrations do you do? Check all that apply.
  ☐ NIST Traceable ☐ Absolute ☐ Relative

- What ancillary data do you collect? Check all that apply.
  ☐ Time & Space Position Information (TiSPI) of Target
  Weather/Atmospheric:
  ☐ Wind speed ☐ Dew point ☐ Humidity ☐ Precipitation
  ☐ CO_2 ☐ Visibility ☐ Temperature ☐ Pressure
  ☐ Other atmospheric data:
  ☐ Other Ancillary Data:

- What are the characteristics of your instruments? (Repeat as needed for each camera, radiometer, reflectometer, monochromator, spectrometer or other instrument that you would like us to know about. See the instructions if you run out of room.)

  - Instrument type:
    Manufacturer/Model:
    Bands or spectral range:
    Frame Rate: Aperture size: f/#:
    Lens(es):
    Year Purchased: Software used:
    How do you calibrate this instrument? ☐ Blackbody, ☐ Common Source, ☐ Internal calibration, ☐ Spectral lamps, ☐ None needed, ☐ Other
    Comments:

  - Instrument type:
    Manufacturer/Model:
    Bands or spectral range:
    Frame Rate: Aperture size: f/#:
    Lens(es):
    Year Purchased: Software used:
    How do you calibrate this instrument? ☐ Blackbody, ☐ Common Source, ☐ Internal calibration, ☐ Spectral lamps, ☐ None needed, ☐ Other
    Comments:

  - Instrument type:
    Manufacturer/Model:
    Bands or spectral range:
    Frame Rate: Aperture size: f/#:
    Lens(es):
    Year Purchased: Software used:
    How do you calibrate this instrument? ☐ Blackbody, ☐ Common Source, ☐ Internal calibration, ☐ Spectral lamps, ☐ None needed, ☐ Other
    Comments:

  - Instrument type:
    Manufacturer/Model:
    Bands or spectral range:
    Frame Rate: Aperture size: f/#:
    Lens(es):
    Year Purchased: Software used:
    How do you calibrate this instrument? ☐ Blackbody, ☐ Common Source, ☐ Internal calibration, ☐ Spectral lamps, ☐ None needed, ☐ Other
    Comments:

- Do you have standard report templates? ☐ Yes ☐ No
  Are you willing to provide a copy of your templates or sample reports? ☐ Yes ☐ No
  Please attach if Yes.

- Do you have documented procedures for Error or Uncertainty Analysis? ☐ Yes ☐ No
  Are you willing to provide a copy of your documented procedures? ☐ Yes ☐ No
  Please attach if Yes.

- What specific items are included in your reports?
  Experimental data**:** ☐ Raw, ☐ Calibrated
  ☐ Data Collection Procedures, ☐ Calibration Procedures, ☐ Calibration Results
  ☐ Modeled data and procedures
  ☐ Theoretical predictions and derivations
  ☐ Uncertainty analysis
  ☐ Other**:**

- Your answers to this survey are:
  ☐ Classified, Classification Level Other:
  ☐ Unclassified ☐ FOUO

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CHAPTER 5

SMSG EO/IR SURVEY RESULTS & INTERPRETATION

This chapter is fundamentally based on a document entitled, *SMSG Project Final Report Draft Version 1*, delivered 12 October 2007 to the SMSG-18 task lead, Mr. Jeffrey W. Burks (EO/IR Laboratory, Code SNS (now Code RYS) at the Air Force Research Laboratory (AFRL), Wright-Patterson AFB. The document was prepared under contract by EO/IR Remote Sensing Group, ATK Space Systems Inc. That document and this chapter summarize the status of the Task SMSG-18 project covering the period from 2 June 2006 to 30 September 2007.

The original project scope covered by the aforementioned report by ATK was to document standards for characterizing the measurement capabilities of EO/IR measurement systems and to help in establishing a demonstration program that verifies and quantifies the improvement in measurement capability that will result from implementing documented standards. Due to technical reasons, part of the original project scope was modified or dropped during the early stage. For example, it was originally intended to define, in draft of the standard, levels of information contents that are synonymous with levels of knowledge as well as the requirements to meet these levels. That requirement was later dropped; however, as much work was done on that part of the effort, the draft results are presented in this SMSG-18 Final Report in Chapter 6, *Draft Document Standards for Characterizing the Measurement Capabilities of EO/IR Measurement Systems*.

Another change was to switch the basis of that report to a document then titled *Development of EO Standard Processes for Application (EOSPA)*, which has been included in this SMSG-18 Final Report as Chapter 7, Draft Handbook for Electro-Optical Measurements. Other modifications on the original project scope are reflected in later sections.

5.1 Introduction

This chapter summarizes the status of the SMSG project covering the period from June 2, 2006 to September 30, 2007. As part of the RCC effort to serve the technical and operational needs of member test ranges or facilities, the SMSG was formed to document signature measurement standards across the electromagnetic (EM) spectrum, specifically in the following areas: radar, millimeter wave (MMW), infrared (IR), laser, visible, ultraviolet (UV), seismic, acoustic, and magnetic. The reported project, officially titled Development of EO Standard Processes for Application (EOSPA), is limited to the EO/IR portion of the EM spectrum.

5.2 Original Project Scope and Modifications

The original project scope covered by the aforementioned ATK report was to document standards for characterizing the measurement capabilities of EO/IR measurement systems and to help in establishing a demonstration program that verifies and quantifies the improvement in measurement capability that will result from implementing documented standards. Due to technical reasons, part of the original project scope was modified or dropped in the early stage. For example, it was originally intended to define, in draft of the standard, levels of information contents that are synonymous with levels of knowledge as well as the requirements to meet these

levels. That requirement was later dropped; however, as much work was done on that part of the effort, the draft results are presented in this SMSG-18 Final Report in Chapter 6, *Draft Document Standards for Characterizing the Measurement Capabilities of EO/OR Measurement Systems*.

Another change was to switch the basis of that report to a document then titled *Development of EO Standard Processes for Application (EOSPA)*, which has been included in this SMSG-18 Final Report as Chapter 7 with its titled changed to *Draft Handbook for Electro-Optical Measurements*. References herein to EOSPA refer to the material contained in Chapter 7. Other modifications on the original project scope are reflected in later sections.

5.3 Sub Tasks

Ten sub tasks were established within the original project scope. Individual sub tasks were detailed in the original SOW (Statement of Work).

5.4 Implementation and Results

5.4.1 Task 1 (EOSPA Draft). It was defined in Task 1 that a draft of EOSPA be prepared and distributed by MRC. The draft was to be based on the sample measurement procedures and reports from member EO/IR ranges or facilities. Early communications among member EO/IR ranges or facilities in attempt to collect or exchange such samples did not produce good results. In part, difficulties were due to the following:

a. The majority of the facilities and programs were classified which made open communication difficult.
b. Significant effort from the member EO/IR ranges was needed to provide the requested information.
c. No agreed-upon sample procedures/reports were distributed as examples of the information requested and many labs were unwilling to share their documents.
d. The SMSG project relied heavily on the format of electronic communications (e-mails and phone calls) and did not plan or allocate budget for travel to allow person-to-person meetings.

Under such circumstances, the first version of the draft of EOSPA in the format of a Microsoft Word document was completed on October 10, 2006. However, no sample procedures or reports from member EO/IR ranges were included since none was available at the time.

5.4.2 Task 2 (Distribution and Survey). As required in Task 2, MRC distributed the first draft of EOSPA with survey/questionnaire to the organizations identified by the RCC to solicit feedback from the same organizations. The survey/questionnaire included questions that will help in identifying an initial set of ranges that are willing to demonstrate the standard procedures

to be documented in the EOSPA draft. Eleven feedbacks were collected after three rounds of survey distributions. The process included:

a. First Distribution. The first version of the draft of EOSPA in the format of a Word document with survey and instructions attached was distributed to about 10 to 15 attendees during a SMSG meeting held in October 17-18, 2006. None of the organizations surveyed sent back feedback.
b. Second Distribution. To make responding to the survey easier, a second version in the form of an Excel spreadsheet was completed on November 27, 2006. The survey was distributed again to the known EO/IR ranges and SMSG members. Feedback from four groups was collected in this round but none of them included sample procedures or reports. One of the respondents was not willing to share its responses with the broader community, so those responses were not included in the tally.
c. Third Distribution. To solicit more feedbacks, the SMSG modified the survey and redistributed it via e-mail during January 10-11, 2007 to about 110 contacts who were involved in EO/IR measurements. Follow-up telephone calls were made to all the contacts. Feedback from seven groups was collected but none of them included sample procedures or reports.
d. Final Sample Request. In an effort to collect sample procedures and reports, e-mail requests and phone calls were made during March 8-19, 2007 to the organizations who responded to the survey. This effort did not produce any results. Some organizations informed MRC that the procedures and reports are for their internal use only. Their management did not approve the request. Other organizations simply said that they did not have any.

5.4.3 Task 3 (First Release). After several round of revisions, MRC complied and distributed a first draft of the EOSPA as reported in paragraph 5.4.1 and paragraph 5.4.2. However, the document was not refined to incorporate any sample procedures or reports since none was collected.

5.4.4 Task 4 (Demo Ranges). None of the EO/IR ranges volunteered to demonstrate the procedures to be documented in the draft. Not completed.

5.4.5 Task 5 (Training). Not completed.

5.4.6 Task 6 (Final Report). This document serves as the final report.

5.4.7 Task 7 (Application). As an example application, the main instrumentation and measurement procedures used in the EO/IR lab were summarized in a report.

5.4.8 Added Task (RF Z540 equivalent). As an additional task, ATK-MR was tasked to produce a document similar to the RF Z540 but more tailored to the EO/IR community, which is included in this Task SMSG-8 Final Report as Chapter 3, *Modified ANSI Z-540.1-1994-based Evaluation Criteria for use by EO/IR Facilities.*

5.5 Major Project Timeline

a. May 19, 2006: MRC received SOW for the SMSG project via e-mail.
b. Jun. 2, 2006: Held SMSG SP50 proposal review/delegation meeting at MRC.
c. Aug. 11, 2006: Completed the first outline for the draft of EOSPA; distributed to NIST for comments.
d. Sept. 19, 2006: Completed the first draft of EOSPA.
e. Oct. 10, 2006: Modified the first draft of EOSPA based on comments from NIST.
f. Oct. 17-18, 2006: Distributed a draft of EOSPA with the first survey/questionnaire to attendees of the SMSG meeting.
g. Nov. 27, 2006: Compiled and distributed the second SMSG survey with instructions
h. Jan. 9-11, 2007: Compiled a SMSA contact list (Excel spreadsheet); distributed the SMSG survey via e-mails; made phone calls to most of the SMSG members on the list.
i. Jan 15, 2007: Wrote a summary on the status of the SMSG project.
j. Feb. 1, 2007: Updated SMSG contact list (Excel spreadsheet) to include only EO/IR members; made phone calls or send e-mails to the EO/IR members on the new list and emphasized Question No.9 in the Survey.
k Mar. 8-19, 2007: Requested sample procedures or reports again from the EO/IR ranges who responded to the surveys via e-mails and phone calls.
l. Sept. 14, 2007: Draft of the final project report
m. Sept. 30, 2007: Final project report

5.6 Survey Results

The information obtained from the collected survey feedback is summarized in this section.

5.6.1 Organizations and POC. The names of POC (Point-of-Contact) who replied to the survey and the organizations with which they were affiliated were originally listed in Table 5-1 of the original ATK/MRC report. To make this Task SMSG-18 Final Report publicly releasable, that information was redacted. Contact the Range Commanders Council Secretariat to learn if that information can be disclosed through other channels. In the table that follows, and in subsequent references in later sections to the participating organizations, generic placeholders are employed.

TABLE 5-1. PARTICIPANT PLACEHOLDER	
No.	**Participant Placeholder**
1	P-1
2	P-2
3	P-3
4	P-4
5	P-5
6	P-6
7	P-7
8	P-8
9	P-9
10	P-A
11	P-B

5.6.2 Types of Targets. Among the organizations who used targets, only P-1 considered background in their tests; P-3 also tested the material of their target; P-8 performed component tests in a fixture as well.

a. Coupons. Organizations that used coupons are listed in Table 5-2.

TABLE 5-2. ORGANIZATIONS USED COUPONS		
Organization	**Coupons**	
	Frequency	**No. of Targets/Yr**
P-2	Common	7
P-4	Occasionally	3
P-7	Occasionally	3
P-8	Common	7
P-A	Occasionally	3
P-B	Common	7

b. Scaled Models. Organizations used scaled models are listed in Table 5-3.

TABLE 5-3. ORGANIZATIONS USED SCALED MODELS			
Organization	**Scaled Models**		
	Frequency	**Targets/Yr**	**Type**
P-1	Occasionally	3	n/a
P-3	Rarely	1	Aircraft, rockets
P-7	Rarely	1	n/a
P-8	Rarely	1	n/a
P-A	Occasionally	3	n/a
P-B	Occasionally	3	n/a

c. Full-Size Target. Organizations that used full-size targets are listed in Table 5-4.

TABLE 5-4. ORGANIZATIONS USED FULL-SIZE TARGETS

Org.	Full Size or Actual Target			
	Frequency	Targets/ Yr	Type	Type
P-1	Common	7	n/a	n/a
P-2	Common	7	n/a	n/a
P-3	Common	7	Plumes, hardbodies, muzzle, flash, high altitude events, launches, intercepts	Plumes, hardbodies, muzzle, flash, high altitude events, launches, intercepts
P-4	Common	7	n/a	n/a
P-6	Common	7	n/a	n/a
P-7	Often	6	n/a	n/a
P-8	Common	7	n/a	n/a
P-9	Common	7	n/a	n/a
P-B	Rarely	Yes	n/a	n/a

5.6.3 Types of Tests. The types of tests conducted by the organizations are summarized in Table 5-5. P-2 reported a maximum test altitude of 500m and maximum test duration of 3min. P-A uses an indoor range for their tests. P-8 also performs other type of tests.

TABLE 5-5. TYPES OF TESTS

Org.	Static	Wind Tunnel	Free Flight	Sled	Wire Guided	Land to Ship	Air to Ship	Air to Gnd	Gnd to Air	Gnd to Gnd	Tower /TT	Moving Target/ Sensor
P-1	No	No	No	No	No	No	No	No	Yes	Yes	No	No
P-2	Yes	No	Yes	No	No	Yes	No	No	No	No	No	No
P-3	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No	No
P-4	No	No	No	No	No	No	No	No	Yes	Yes	Yes	No
P-5	No	No	No	No	No	No	No	No	No	No	No	No
P-6	Yes	No	No	No	No	No	Yes	Yes	Yes	Yes	No	Yes
P-7	Yes	No	No	No	No	No	No	No	Yes	Yes	No	No
P-8	Yes	No	No	No	No	No	No	No	No	No	No	No
P-9	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
P-A	No	No	No	No	No	No	No	No	No	No	No	No
P-B	Yes	No	No	No	No	No	No	No	Yes	Yes	No	No

5.6.4 Types of Measurements. The type of measurements performed by the organizations is summarized in Table 5-6. Measurement temperature range and the sensors used to monitor the temperature are shown in Table 5-7.

TABLE 5-6. TYPES OF MEASUREMENT

Organization	Radiometric	Images	Spectral	Spectral Images	Polarization	Reflectance	Transmittance
P-1	Yes	Yes	Yes	No	No	Yes	No
P-2	Yes	Yes	Yes	No	No	Yes	Yes
P-3	Yes	Yes	Yes	No	No	No	No
P-4	Yes	Yes	Yes	Yes	No	Yes	No
P-5	No	No	No	No	No	No	No
P-6	Yes	Yes	Yes	Yes	No	No	No
P-7	Yes	Yes	Yes	No	No	No	No
P-8	Yes	Yes	No	No	No	Yes	Yes
P-9	No	Yes	Yes	Yes	No	No	No
P-A	Yes	Yes	Yes	No	No	Yes	Yes
P-B	Yes	Yes	Yes	Yes	Yes	Yes	Yes

TABLE 5-7. TEMPERATURE RANGE AND SENSORS

Organization	Temperature Range		Thermocouple/Types						RTD		Target Illumination
	Min (^oC)	Max (^oC)	Yes/No	K	T	J	E	I-buttons	Yes/No	Type	
P-1	n/a	n/a	Yes	Yes	No	No	No	Yes	No	n/a	No
P-2	200	3000	No	No	No	No	No	No	No	n/a	No
P-3	n/a	n/a	No	No	No	No	No	No	No	n/a	No
P-4	n/a	n/a	Yes	Yes	Yes	No	No	No	No	n/a	No
P-5	n/a	n/a	No	No	No	No	No	No	No	n/a	No
P-6	-20	50	No	No	No	No	No	No	No	n/a	Yes
P-7	n/a	n/a	No	No	No	No	No	No	No	n/a	No
P-8	n/a	n/a	No	No	No	No	No	No	No	n/a	No
P-9	n/a	n/a	No	No	No	No	No	No	No	n/a	No
P-A	n/a	n/a	Yes	No	No	No	Yes	No	Yes	100□	No
P-B	-40	1200	Yes	Yes	Yes	Yes	No	No	Yes	n/a	No

5.6.5 Calibration Sources. The types of calibration sources used by the organizations are listed in Table 5-8.

TABLE 5-8. CALIBRATION SOURCES

TABLE 5-8. CALIBRATION SOURCES

Org.	Blackbody				Common Source	Spectral Lamps		D2 Lamps	Reflectance Panels	Other Sources
	Yes/ No	T_{min} (^oC)	T_{max} (^oC)	Max Size (in)	Yes/No	Yes/No	Type	Yes/No		
P-1	1	-40	1400	30 by 30	No	Yes	-	No	No	No
P-2	1	-20	550	12 by 12	No	Yes	n/a	Yes	No	No
P-3	1	10	1200	6	Yes	Yes	n/a	No	No	No
P-4	1	-10	600	12 by 12	Yes	No	n/a	No	No	No
P-5	0	n/a	n/a	n/a	No	No	n/a	No	No	No
P-6	1	varies	varies	12	No	No	n/a	No	Yes	No
P-7	1	Ambient	600	12	No	No	n/a	No	No	No
P-8	0	n/a	n/a	n/a	No	No	n/a	No	No	Yes
P-9	0	n/a	n/a	n/a	No	No	n/a	No	No	No
P-A	1	-100	1300	6 by 6	No	No	n/a	No	No	No
P-B	1	20	1000	4	Yes	Yes	n/a	No	No	No

5.6.6 Calibration Type. The calibration type is summarized in Table 5-9.

TABLE 5-9. CALIBRATION TYPE

Organization	NIST Traceable	Absolute	Relative
P-1	Yes	Yes	Yes
P-2	Yes	Yes	Yes
P-3	Yes	Yes	Yes
P-4	Yes	Yes	Yes
P-5	Yes	No	No
P-6	Yes	Yes	Yes
P-7	Yes	No	Yes
P-8	No	Yes	Yes
P-9	No	No	No
P-A	Yes	No	No
P-B	Yes	Yes	Yes

5.6.7 Data Collected. The types of data collected by the organizations are listed in Table 5-10, Table 5-11, and Table 5-12.

TABLE 5-10. ENVIRONMENTAL DATA COLLECTED

Org.	TSPI*	Wind Speed	Dew Point	Humidity	Precip	Visibility	Temp	Pressure	Other Atmospheric Data
P-1	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	n/a
P-2	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	n/a
P-3	No	Yes	Yes	Yes	No	No	Yes	Yes	n/a
P-4	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	n/a
P-5	No	No	No	No	No	No	No	No	n/a
P-6	Yes	Yes	Yes	No	Yes	Yes	No	Yes	n/a
P-7	Yes	Yes	Yes	Yes	Yes	No	No	No	n/a
P-8	Yes	No	No	No	No	No	No	No	n/a
P-9	Yes	Yes	No	Yes	No	No	Yes	Yes	n/a
P-A	No	No	No	Yes	No	No	Yes	No	n/a
P-B	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Variation with altitude

* TSPI = time-space-position-information

TABLE 5-11. BACKGROUND DATA COLLECTED

Organization	Nephelometer	Gnd Temperature	Soil Moisture Content	Cloud Data
P-1	No	No	No	No
P-2	Yes	No	No	No
P-3	No	No	No	No
P-4	No	Yes	Yes	Yes
P-5	No	No	No	No
P-6	No	No	No	No
P-7	No	No	No	No
P-8	No	No	No	No
P-9	No	No	No	No
P-A	No	No	No	No
P-B	No	No	No	No

TABLE 5-12. SPECTRAL OR RADIOMETRIC DATA COLLECTED						
Organization	**CO_2**	**IR Radiation**	**Solar Irradiance**	**Ozone**	**CN2**	**Background Spectra**
P-1	No	Yes	Yes	No	No	No
P-2	No	No	Yes	Yes	No	No
P-3	Yes	No	No	Yes	No	No
P-4	No	No	No	No	No	No
P-5	No	No	No	No	No	No
P-6	Yes	No	Yes	No	Yes	No
P-7	No	No	No	No	No	No
P-8	No	No	No	No	No	No
P-9	No	No	No	No	No	No
P-A	No	No	No	No	No	No
P-B	No	No	No	No	No	Yes

5.6.8 Report.

a. Templates and Samples. Survey results on the usage of report template are listed in Table 5-13. Three organizations said that they have samples but none of them shared their documents with MRC.

b. Error or Uncertainty Analysis. As shown in Table 5-13, only three organizations perform error or uncertainty analysis. Although P-B had samples, they did not share them.

TABLE 5-13. REPORT TEMPLATES AND SAMPLES			
Org.	**Report Template**		
	Existing?	**Sample?**	**Shared?**
P-1	No	No	No
P-2	Yes	No	No
P-3	Yes	No	No
P-4	No	Yes	No
P-5	No	No	No
P-6	No	No	No
P-7	Yes	Yes	No
P-8	Yes	No	No
P-9	No	No	No
P-A	No	No	No
P-B	Yes	Yes	No

TABLE 5-14. ERROR OR UNCERTAINTY ANALYSIS			
Org.	**Error/Uncertainty Analysis**		
	Doc Procedure?	**Sample?**	**Shared?**
P-1	No	No	No
P-2	No	No	No
P-3	Yes	No	No
P-4	No	No	No
P-5	Yes	No	No
P-6	No	No	No
P-7	No	No	No
P-8	No	No	No
P-9	No	No	No
P-A	No	No	No
P-B	Yes	Yes	No

c. Data Types, Procedures, and Results. Data types, procedures, and results in the report are listed in Table 5-15.

TABLE 5-15. DATA TYPES, PROCEDURES, AND RESULTS REPORTED

Org.	Data Type Reported				Procedures Reported			Results Reported
	Raw	Calibrated	Modeled	Uncertainty Analysis	Data Acquisition	Calibration	Data Modeling	Calibration Results
P-1	Yes	Yes	No	No	Yes	Yes	No	Yes
P-2	No	Yes	Yes	Yes	Yes	Yes	Yes	No
P-3	Yes	Yes	No	No	Yes	Yes	No	Yes
P-4	No	Yes	Yes	No	Yes	Yes	Yes	No
P-5	No	No	No	No	No	No	No	No
P-6	Yes	Yes	Yes	No	Yes	No	Yes	No
P-7	Yes	Yes	No	No	Yes	Yes	No	Yes
P-8	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
P-9	No	No	No	No	No	No	No	No
P-A	No	Yes	No	No	Yes	Yes	No	Yes
P-B	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes

d. Other Contents. Other contents in report are listed in Table 5-16.

TABLE 5-16. OTHER CONTENTS IN THE REPORT

Organization	Imagery Database	Theoretical Predictions and Derivations	Metadata	Analysis of Items Under Test	Sample History
P-1	No	No	No	No	No
P-2	No	No	No	No	No
P-3	No	No	No	No	No
P-4	Yes	No	No	No	No
P-5	No	No	No	No	No
P-6	No	Yes	No	No	No
P-7	No	Yes	Yes	No	No
P-8	No	Yes	No	Yes	No
P-9	No	No	No	No	No
P-A	No	No	No	No	No
P-B	No	Yes	No	No	Yes

5.6.9 Classification. The classification assigned by each organization to their survey reply is listed in Table 5-17.

TABLE 5-17. SURVEY CLASSIFICATION

	Survey is		Distribution					
			Approved for public release?	Authorized to US Government Agencies and their contractors?			Authorized to the DoD and their Contractors	Export Control Warning
Org.	Unclass	FOUO		Yes/No	Reason	Date of determination		
P-1	Yes	Yes	No	No	n/a	n/a	No	No
P-2	Yes	Yes	No	No	n/a	n/a	No	No
P-3	Yes	No	Yes	No	n/a	n/a	No	No
P-4	No	Yes	No	Yes	Critical technology	Dec-06	No	No
P-5	Yes	No	Yes	No	n/a	n/a	No	No
P-6	Yes	Yes	Yes	Yes	n/a	n/a	No	No
P-7	Yes	No	Yes	No	n/a	n/a	No	No
P-8	Yes	No	Yes	No	n/a	n/a	No	No
P-9	Yes	No	No	No	n/a	n/a	Yes	No
P-A	Yes	No	No	No	No	No	Yes	No
P-B	No	Yes	No	No	No	No	No	Yes

5.6.10 Instruments. Types of instruments with major specifications, the suppliers, and owners are listed in the tables in this section.

a. Colorimeter or Photometer.

TABLE 5-18. COLORIMETER OR PHOTOMETER

Supplier	Model	Spectral Range (μm)	Owner	Qty (unit)
Photo Research	PR650	0.38 - 0.78	P-1	1
Photo Research	PR880	Vis	P-1	1

b. Radiometer.

(1) NIR Band. NIR radiometers with major characteristics with their owners are listed in Table 5-19. Accessories and other information are listed in Table 5-20.

TABLE 5-19. NIR RADIOMETERS AND SPECIFICATIONS

Supplier	Radiometer Model	Det	Det Size	Spectral Range (µm)	Frame Rate (Hz)	Filter Pass Bands (µm)	Owner	Qty (Units)
P-3	UV Rad 1	CsTe	n/a	0.01 - 0.4	< 20000	0.2 - 0.4	P-3	1
P-3	UV Rad 2	CsTe	n/a	0.01 - 0.4	< 20000	0.2 - 0.4	P-3	1
P-3	UV Rad 3	MCP	n/a	0.01 - 0.4	< 20000	0.2 - 0.4	P-3	1
P-3	Rad 7	InSb	1 mm chip	Dual band	< 20000	1.0 - 5.0	P-3	1
P-3	Rad 8	InSb	1 mm chip	Dual band	< 20000	1.0 - 5.0	P-3	1
P-3	Rad 9	InSb	1 mm chip	Dual band	< 20000	1.0 - 5.0	P-3	1
P-3	Rad 10	InSb	1 mm chip	Dual band	< 20000	1.0 - 5.0	P-3	1
P-3	Rad 11	InSb	1 mm chip	Dual band	< 20000	1.0 - 5.0	P-3	1
Xybion	Xybion	InSb	1 mm chip	Dual band	n/a	UV - Vis	P-3	1
Xybion	Xybion	n/a	n/a	0.4 - 0.9	Varies	n/a	P-4	1
Magnavox	Magnavox	n/a	n/a	Dual band	30	n/a	P-4	1
CEDIP	CEDIP	n/a	n/a	1.2 - 3	Varies	n/a	P-4	1

TABLE 5-20. NIR RADIOMETER ACCESSORIES AND OTHER INFORMATION

Supplier	Radiometer Model	Lenses/ FOV	Year of Purchase	Bit Depth (bit)	Software	Calibrated with	Comment	Owner
P-3	UV Rad 1	9 deg	2000	n/a	Custom	Spectral lamps	CsTe PMT, Analog	P-3
P-3	UV Rad 2	25 deg	2001	n/a	Custom	Spectral lamps	CsTe PMT, Photon counter	P-3
P-3	UV Rad 3	9, 25 deg	2001	n/a	Custom	Spectral lamps	MCP intensifier	P-3
P-3	Rad 7	2 and 7 deg	2000	n/a	Custom (LabVIEW/ MATLAB)	BB	Single 1 mm InSb det	P-3
P-3	Rad 8	2 and 7 deg	2000	n/a	Custom (LabVIEW/ MATLAB)	BB	Single 1 mm InSb det	P-3
P-3	Rad 9	2 and 7 deg	2000	n/a	Custom (LabVIEW/ MATLAB)	BB	Single 1 mm InSb det	P-3
P-3	Rad 10	2 and 7 deg	2000	n/a	Custom (LabVIEW/ MATLAB)	BB	Single 1 mm InSb det	P-3
P-3	Rad 11	2 and 7 deg	2000	n/a	Custom (LabVIEW/ MATLAB)	BB	Single 1 mm InSb det	P-3
Xybion	Xybion	13mm-5080mm selectable, variable	1997	n/a	HW specific	Spectral lamps	Single 1mm InSb	P-3
Xybion	Xybion	f/# 1.4	2004	n/a	Custom	Other	Computer controlled gain/exposure	P-4
Magnavox	Magnavox	Aperture size 12"; f/# 1.4	1989	n/a	In-house	BB	n/a	P-4
CEDIP	CEDIP	n/a	2004	n/a	Custom	Other	n/a	P-4

(2) Mid-wavelength Infrared (MWIR) Band. MWIR radiometers with major characteristics with their owners are listed in Table 5-21. Other parameters and information are in Table 5-22.

TABLE 5-21. MWIR RADIOMETERS AND SPECIFICATIONS

Supplier	Model	Det	Array Size	Spectral Range (μm)	Frame Rate (Hz)	Owner	Qty
Amber	Galileo	InSb	256 x 256	3 - 5	120	P-1	3
Inframetrics	760	Scanning MTC	257 x 207	3 - 5	30	P-1	2
Electrophysics	Jade MW	MCT	320 x 240	3 - 5	200	P-1	1
Electrophysics	Emerald MW	MCT	640 x 512	3 - 5	100	P-1	1
Inframetrics	PM 390	PtSi	n/a	3 - 5	30	P-1	1

TABLE 5-22. OTHER PARAMETERS AND INFORMATION FOR THE MWIR RADIOMETERS

Supplier	Model	Bit Depth (bit)	Software	Calibrated with	Owner
Amber	Galileo	12	Custom LabVIEW	Blackbodies	P-1
Inframetrics	760	8	Thermagram (old DOS version)	Blackbodies	P-1
Electrophysics	Jade MW	14	Altair	Blackbodies	P-1
Electrophysics	Emerald MW	14	Altair	Blackbodies	P-1
Inframetrics	PM 390	8	None	None	P-1

(3) Long-wavelength Infrared (LWIR) Radiometers. LWIR radiometers with major characteristics and their owners are listed in Table 5-23. Other parameters and information are listed in Table 5-24.

TABLE 5-23 LWIR RADIOMETERS AND SPECIFICATIONS

Supplier	Model	Det	Array Size	Spectral Range (μm)	Frame Rate (Hz)	Owner	Qty
Indigo	Merlin Uncooled	Microbolometer	320 x 240	7 - 14	30	P-1	3
Amber/Raytheon	Radiance 1	QWIP	256 x 256	8 - 9.2	60	P-1	1
Inframetrics	760	Scanning MTC	257 x 207	8 - 12	30	P-1	3
Electrophysics	Jade LW	MCT	320 x 240	7 - 9.2	200	P-1	1
FLIR	ThermaCam EX 320	Microbolometer	(320 x 240)	(7.5 - 13)	n/a	P-1	1

TABLE 5-24. OTHER PARAMETERS AND INFORMATION FOR THE LWIR RADIOMETERS

Supplier	Model	Bit Depth (bit)	Software	Calibrated with	Owner
Indigo	Merlin Uncooled	12	Custom LabVIEW	Blackbodies	P-1
Amber/Raytheon	Radiance 1	12	Rtools	Blackbodies	P-1
Inframetrics	760	8	Thermagram (old DOS version)	Blackbodies	P-1
Electrophysics	Jade LW	14	Altair	Blackbodies	P-1
FLIR	ThermaCam EX 320	12	ThermaCAM QuickView	Blackbodies	P-1

c. Hyperspectral Radiometers. Hyperspectral radiometers with major characteristics and their owners are listed in Table 5-25. Other parameters and information are listed in Table 5-26.

TABLE 5-25. HYPERSPECTRAL RADIOMETERS AND SPECIFICATIONS

Supplier	Radiometer Model	Detector Model	Det	Array Size	Spectral Range (μm)	Frame Rate (Hz)	Owner	Qty (Unit)
Pacific Advanced Technology	LW IMSS	Radiance 1	QWIP	256 x 256	8 - 9.2	n/a	P-1	1
Pacific Advanced Technology	MW IMSS	Galileo	InSb	256 x 256	3 - 5	n/a	P-1	1
n/a	Custom	n/a	n/a	n/a	Dual band	n/a	P-4	1
n/a	Custom	n/a	n/a	n/a	0.4 - 0.77	Varies	P-4	1

TABLE 5-26. OTHER PARAMETERS AND INFORMATION FOR THE HYPERSPECTRAL RADIOMETERS

Supplier	Radiometer Model	Bit Depth (bit)	Software	Calibrated with	Year of Purchase	Comments	Owner
Pacific Advanced Technology	LW IMSS	12	n/a	n/a	n/a	n/a	P-1
Pacific Advanced Technology	MW IMSS	12	n/a	n/a	n/a	n/a	P-1
n/a	Custom	n/a	Custom	BB, Spectral lamps	2005	Hyperspectral GSMS systems collect 2-Datacubes/sec	P-4
n/a	Custom	n/a	Custom	Field source	2004	M2100	P-4

d. Imaging Radiometers. Imaging radiometers with major characteristics and their owners are listed in Table 5-27. Other parameters and information are listed in Table 5-28.

TABLE 5-27. IMAGING RADIOMETERS AND SPECIFICATIONS

Supplier	Model	Det	Array Size	Spectral Range (µm)	Frame Rate (Hz)	Filter Pass Bands (µm)	Owner	Qty (Unit)
Indigo	Merlin NIR	VisGaAs	320 x 240	0.6 - 1.7	< 60	n/a	P-1	1
Indigo	Phoenix	n/a	n/a	other	< 60	n/a	P-2	1
FLIR	SC6000	n/a	n/a	other	< 60	n/a	P-2	1
FLIR	SC2000	n/a	n/a	6 - 40	< 60	n/a	P-2	1
Basler	n/a	n/a	n/a	0.4 - 0.77	< 500	n/a	P-3	1
FLIR	SC6000	InSb	640 x 512	3 - 6	< 1500	3 - 5	P-3	1
FLIR	SC6000	InSb	640 x 512	3 - 6	< 1500	3.4 - 4.1	P-3	1
FLIR	SC6000	InGaAs	640 x 512	Dual bands	< 1500	0.65 - 1.7	P-3	1
Indigo	Alpha NIR	InGaAs	320 x 256	Dual bands	< 30	0.9 - 1.7	P-3	1
Indigo	Bolometer	Bolometer	320 x 240	6 - 40	< 60	8 - 12	P-3	1
Indigo	Merlin	QWIP	320 x 256	6 - 40	< 60	8 - 9	P-3	1
n/a	Phantom 9	n/a	1600 x 1200	0.4 - 1.7	< 144000	0.9 - 1.7	P-3	1
Photron	Ultima APXi2 Fastcam	n/a	1024 x 1024	Dual bands	< 2000	0.25 - 1.0	P-3	1
Santa Barbara	FPA SB#1	InSb	320 x 256	Dual bands	< 613	1.0 - 5.0	P-3	1
Santa Barbara	FPA SB#2	InSb	320 x 256	Dual bands	< 613	1.0 - 5.0	P-3	1
Santa Barbara	FPA SB#3	InSb	320 x 256	Dual bands	< 613	1.0 - 5.0	P-3	1
Santa Barbara	FPA SB#4	InSb	320 x 256	Dual bands	< 613	1.0 - 5.0	P-3	1
Santa Barbara	FPA SB#5A	InSb	640 x 512	Dual bands	< 1500	1.0 - 5.0	P-3	1
Santa Barbara	FPA SB#5B	InSb	640 x 512	Dual bands	< 1500	1.0 - 5.0	P-3	1
Santa Barbara	FPA SB#5C	InSb	640 x 512	Dual bands	< 1500	1.0 - 5.0	P-3	1
Santa Barbara	FPA SBLW1	QWIP	320 x 256	6 - 40	< 1200	8.0 - 9.0	P-3	1
Santa Barbara	FPA SBLW2	QWIP	320 x 256	6 - 40	< 1200	8.0 - 9.0	P-3	1
Sony	Sony	n/a	630 x 480	Dual bands	< 30	Vis - NIR	P-3	1
Amber	Galileo	InSb	256 x 256	3 - 5	120	n/a	P-1	3
Inframetrics	760	Scanning MTC	257 x 207	3 - 5	30	n/a	P-1	2
Electrophysics	Jade MW	MCT	320 x 240	3 - 5	200	n/a	P-1	1
Electrophysics	Emerald MW	MCT	640 x 512	3 - 5	100	n/a	P-1	1
Inframetrics	PM 390	PtSi	n/a	3 - 5	30	n/a	P-1	1
Indigo	Merlin Uncooled	Microbolometer	320 x 240	7 - 14	30	n/a	P-1	3
Amber/ Raytheon	Radiance 1	QWIP	256 x 256	8 - 9.2	60	n/a	P-1	1
Inframetrics	760	Scanning MTC	257 x 207	8 - 12	30	n/a	P-1	1
Electrophysics	Jade LW	MCT	320 x 240	7 - 9.2	200	n/a	P-1	1
FLIR	ThermaCam EX 320	Microbolometer	(320 x 240)	(7.5 - 13)	n/a	n/a	P-1	1

TABLE 5-27. IMAGING RADIOMETERS AND SPECIFICATIONS

Supplier	Model	Det	Array Size	Spectral Range (µm)	Frame Rate (Hz)	Filter Pass Bands (µm)	Owner	Qty (Unit)
Agema	Agema	n/a	n/a	Dual band	25	n/a	P-4	1
FLIR	n/a	n/a	n/a	Dual band	Varied	n/a	P-7	1
Santa Barbara	FPA	n/a	n/a	Dual band	Varied	n/a	P-7	1
Santa Barbara	FPA	n/a	n/a	Dual band	Varied	n/a	P-7	2
Santa Barbara	FPA LWIR	n/a	n/a	6 - 40	Varied	n/a	P-7	1
CEDIP	Jade VLWIR	n/a	320 x 240	6 - 40	200 (full), 600 (sub)	8.0 - 11.5	P-A	1
Santa Barbara	FPA	InSb	640 x 512	3 - 6	157	1 - 5.5	P-A	1
Agema	Agema 570	Microbolometer	320 x 240	6 - 40	60	7.5 - 13	P-A	1
FLIR	SC3000	QWIP	320 x 240	Other	900	8 - 9	P-A	1
FLIR	ThermaCam S65HS	n/a	320 x 240	7.5 - 13	60	n/a	P-B	1
Inframetrics	ThermaCam PM380	n/a	256 x 256	3.4 - 5	60	n/a	P-B	1
Inframetrics	760	n/a	194 x 256	Dual band	60	n/a	P-B	1

TABLE 5-28. OTHER PARAMETERS AND INFORMATION FOR THE IMAGING RADIOMETERS

Supplier	Model	Aperture/ Lenses/FOV	Year of Purch	Bit Depth (bit)	Software	Calibrated with	Comments	Owner
Indigo	Merlin NIR	n/a	n/a	14	Rtools	Integrating Sphere	n/a	P-1
Indigo	Phoenix	Janos 16, 8, 4, 2 deg	n/a	n/a	Rtools	BB	Superframing capability	P-2
FLIR	SC6000	Janos 16, 4, 2 deg	2006	n/a	Rtools	BB	Superframing capability	P-2
FLIR	SC2000	24, 12, 7, 5 deg	1997 used	n/a	Rtools	BB	n/a	P-2
Basler	n/a	13 mm - 5080 mm selectable	2005	n/a	HW specific	Spectral lamps	n/a	P-3
FLIR	SC6000	13 mm - 5080 mm selectable, 0.11 - 52 deg	2007	n/a	Rtools	BB	n/a	P-3
FLIR	SC6000	13 mm - 5080 mm selectable, 0.11 - 52 deg	2007	n/a	Rtools	BB	n/a	P-3
FLIR	SC6000	13 mm - 5080 mm selectable, 0.11 - 52 deg	2007	n/a	Rtools	BB	n/a	P-3
Indigo	Alpha NIR	13 mm - 5080 mm selectable, variable	2000	n/a	Camdaq/ Hyperview	BB, spectral lamps	n/a	P-3
Indigo	Bolometer	13, 25, 50, 100 mm selectable	2001	n/a	Camdaq/ Hyperview	BB	n/a	P-3
Indigo	Merlin	13 mm - 5080 mm selectable, 0.88, 4.4, 34 deg	2002	n/a	Camdaq/ Hyperview	BB	n/a	P-3
n/a	Phantom 9	13 mm - 5080 mm selectable, variable	2005	n/a	HW specific	Spectral lamps	n/a	P-3
Photron	Ultima APXi2 Fastcam	13 mm - 5080 mm selectable, variable	2006	n/a	FastCam, custom	Spectral lamps	UV enhanced intensified	P-3
Santa Barbara	FPA SB#1	13 mm - 5080 mm selectable, 0.11 - 34 deg	n/a	n/a	CamDaq/Rtools	BB	FPA	P-3
Santa Barbara	FPA SB#2	13 mm - 5080 mm selectable, 0.11 - 34 deg	n/a	n/a	CamDaq/ Rtools	BB	FPA	P-3
Santa Barbara	FPA SB#3	13 mm - 5080 mm selectable, 0.11 - 34 deg	n/a	n/a	CamDaq/Rtools	BB	FPA	P-3
Santa Barbara	FPA SB#4	13 mm - 5080 mm selectable, 0.11 - 34 deg	n/a	n/a	CamDaq/Rtools	BB	FPA	P-3
Santa Barbara	FPA SB#5A	13 mm - 5080 mm selectable, 0.11 - 52 deg	2004	n/a	CamDaq/Rtools /WinIR	BB	SBFP MWIR	P-3
Santa Barbara	FPA SB#5B	13 mm - 5080 mm selectable, 0.11 - 52 deg	2004	n/a	CamDaq/Rtools /WinIR	BB	SBFP MWIR	P-3
Santa Barbara	FPA SB#5C	13 mm - 5080 mm selectable, 0.11 - 52 deg	2004	n/a	CamDaq/Rtools /WinIR	BB	SBFP MWIR	P-3
Santa Barbara	FPA SBLW1	13 mm - 5080 mm selectable, 0.88 - 5.5 deg	2006	n/a	WinIR	BB	SB QWIP	P-3
Santa Barbara	FPA SBLW2	13 mm - 5080 mm selectable, 0.88 - 5.5 deg	2007	n/a	WinIR	BB	SB QWIP	P-3

TABLE 5-28. OTHER PARAMETERS AND INFORMATION FOR THE IMAGING RADIOMETERS

Supplier	Model	Aperture/ Lenses/FOV	Year of Purch	Bit Depth (bit)	Software	Calibrated with	Comments	Owner
Sony	Sony	13 mm - 5080 mm selectable, Variable	2001	n/a	CamDaq/ Hyperview	Spectral lamps	Sony 630 x 480	P-3
Amber	Galileo	n/a	n/a	12	Custom LabVIEW	BB	n/a	P-1
Inframetrics	760	n/a	n/a	8	Thermagram (old DOS version)	BB	n/a	P-1
Electrophysics	Jade MW	n/a	n/a	14	Altair	BB	n/a	P-1
Electrophysics	Emerald MW	n/a	n/a	14	Altair	BB	n/a	P-1
Inframetrics	PM 390	n/a	n/a	8	None	None	n/a	P-1
Indigo	Merlin Uncooled	n/a	n/a	12	Custom LabVIEW	BB	n/a	P-1
Amber/ Raytheon	Radiance 1	n/a	n/a	12	Rtools	BB	n/a	P-1
Inframetrics	760	n/a	n/a	8	Thermagram (old DOS version)	BB	n/a	P-1
Electrophysics	Jade LW	n/a	n/a	14	Altair	BB	n/a	P-1
FLIR	ThermaCam EX 320	n/a	n/a	12	ThermaCAM QuickView	BB	n/a	P-1
Agema	Agema	n/a	2004	n/a	Custom	BB	n/a	P-4
FLIR	n/a	Varied	2005	n/a	Rtools/In-house	BB	n/a	P-7
Santa Barbara	FPA	Varied	2000	n/a	Rtools/In-house	BB	n/a	P-7
Santa Barbara	FPA	Varied	2002	n/a	Rtools/In-house	BB	n/a	P-7
Santa Barbara	FPA LWIR	Varied	2002	n/a	Rtools/In-house	BB	n/a	P-7
CEDIP	Jade VLWIR	25 mm; f/# 2.0	2006	n/a	Rtools/Altair	BB	Stirling cooled; filter wheel	P-A
Santa Barbara	FPA	25, 50, 100 mm; f/# 2.3	2002	n/a	Rtools	BB	LN2 cooled; filter wheel	P-A
Agema	Agema 570	24 x 18 deg, 12 x 9 deg	1997	n/a	FSI	BB	No filters	P-A
FLIR	SC3000	20 x 15 deg	1999	n/a	FSI	BB	n/a	P-A
FLIR	ThermaCam S65HS	Aperture Size 48 mm; 120 mm, 36 mm, f/# 0.75	2005	n/a	ThermaCam Researcher/ Quickview	BB	n/a	P-B
Inframetrics	ThermaCam PM380	8 and 16 deg FOV; f/1.5	1996	n/a	Thermagram	BB, internal calibration	n/a	P-B
Inframetrics	760	0.5" aperture; 15x20 deg; 3X, 10X zoom	1990	n/a	Thermagram	BB, internal calibration	scanned strip; vender calibration	P-B

e. Spectral Radiometer. Spectral radiometers with major characteristics and their owners are listed in Table 5-29. Other parameters and information are listed in Table 5-30.

TABLE 5-29. SPECTRAL RADIOMETER AND SPECIFICATIONS

Supplier	Model	Det	Spectral Range (µm)	Filter Pass Bands (µm)	Frame Rate (Hz)	Owner	Qty (Unit)
ABB Bomem	FTIR MR254	InSb; MCT	1.3 - 13	n/a	10 Hz @ 1 wave-number	P-1	2
CI Systems	SR5000	InSb; MCT; SiPbS	1.3 - 14.5; 0.4 - 2.2	n/a	10 Hz Spectral; 1 kHz Staring	P-1	2
ABB Bomem	MR304SC	n/a	Dual bands	n/a	< 82 spectra per sec	P-2	1
SciTec	8145	n/a	0.1 - 1.7	n/a	< 100 k	P-2	1
Pacific Sierra Research	SRS	n/a	0.35 - 1.1	n/a	< 60	P-2	1
ABB Bomem	MR254	n/a	Dual bands	n/a	10 - 82	P-3	1
ABB Bomem	MR255	n/a	Dual bands	n/a	10 - 82	P-3	1
P-3	High Speed UV Spectrometer	n/a	0.01 - 0.4	0.25 -0.29	< 500	P-3	1
PIMAX	1340 Pixis Visible Spectrometer	n/a	0.4 - 0.77	0.3 - 1.0	< 183	P-3	1
PIMAX	1024 Pixis UV-Vis Spectrometer	n/a	0.01 - 0.4	0.2 - 0.9	< 183	P-3	1
Zeiss	Zeiss Spectrometer	n/a	Dual bands	0.2 - 1.0	< 95	P-3	1
CI Systems	CI Systems	n/a	Other	n/a	Varies	P-4	1
Bomem	n/a	n/a	Other	n/a	n/a	P-7	2
Cary	5E UV-VIS-NIR Spectrometer	n/a	0.18 - 2.5	n/a	n/a	P-B	1
Thermal Electron	Nicolet Magna	n/a	2.5 - 25	n/a	n/a	P-B	1

TABLE 5-30. OTHER PARAMETERS AND INFORMATION FOR THE SPECTRAL RADIOMETERS

Supplier	Model	Lenses / FOV	Resolution (cm^{-1})	Year Purchased	Software	Calibration Sources	Comments	Owner
ABB Bomem	FTIR MR254	n/a	n/a	n/a	n/a	n/a	n/a	P-1
CI Systems	SR5000	n/a	n/a	n/a	n/a	n/a	n/a	P-1
ABB Bomem	MR304SC	3	n/a	2004	Written-in-house	BB, spectral lamps	n/a	P-2
SciTec	8145	None	n/a	2003	Custom built in C++	Done at SciTec	n/a	P-2
Pacific Sierra Research	SRS	14mm, 19mm, 72mm, 238mm, 540mm	n/a	1996 (upgraded 2006)	Custom built in LabVIEW	Spectral lamps, common sources	n/a	P-2
ABB Bomem	MR254	0.1, 1.0, 2.5 deg	1, 2, 4, 8, 16	2000	Bomem & Custom	BB, spectral lamps	2 ch, 3 det options (Ge, InSb, HgCdTe)	P-3
ABB Bomem	MR255	0.1, 1.0, 2.5 deg	1, 2, 4, 8, 16	2001	n/a	BB, spectral lamps	2 ch, 3 det options (Ge, InSb, HgCdTe)	P-3
P-3	High Speed UV Spectrometer	Variable optics, 2.5 deg	1 nm	2000	HW specific	Spectral lamps	Proxitronic ASB intensifier 1 x 128	P-3
PIMAX	1340 Pixis Visible Spectrometer	Variable optics, 0.25 to 5 deg	0.11 - 2.5 nm	2006	HW specific	Spectral lamps	Camera: Pixis 1340 x 100	P-3
PIMAX	1024 Pixis UV-Vis Spectrometer	Variable optics, 0.25 to 5 deg	0.11 - 2.5 nm	2006	HW specific	Spectral lamps	Camera: Pixis 1024 x 256 UV enhanced intensified	P-3
Zeiss	Zeiss Spectrometer	0.3 deg	2.3 nm	1999	HW specific	Spectral lamps	Zeiss Spectrometer 1 x 1024	P-3
CI Systems	CI Systems	n/a	0.4 - 14 μm	1998	Custom	BB, Other	0.4 - 14 micrometers	P-4
Bomem	n/a	Varied	n/a	2004	Rtools/Acquire/In-house	BB	n/a	P-7
Cary	5E UV-VIS-NIR Spectrometer	n/a	n/a	1993	ADL (Varian proprietary)	Reference coupons, vender	Commercial system with DHR, BRDF, BTDF attachments; DHR sample port size 1", 1.25"	P-B
Thermal Electron	Nicolet Magna	n/a	n/a	1994	Omnic	Reference coupons, vender	Commercial system with DHR, BRDF, BTDF attachments; DHR sample port size 0.875"	P-B

f. Reflectometer. Reflectometers with major characteristics and their owners are listed in Table 5-31. Other parameters and information are listed in Table 5-32. Comments on the reflectometers are listed in Table 5-33.

TABLE 5-31. REFLECTOMETERS AND SPECIFICATIONS

Supplier	Model	Spectral Range (μm)	Sample Spot Size	Owner	Qty (Unit)
Surface Optics	SOC-400T	2 - 25	n/a	P-1	1
Analytical Spectral Devices	Fieldspec-FR	0.3 - 2.5	n/a	P-1	1
P-B	Imaging Sphere	0.4 - 12	0.375"; f/23	P-B	1
P-B	Imaging Sphere Environmental	0.4 - 12	0.375"; f/23	P-B	1
P-B	Portable Reflectometer 1	0.4 - 12	0.375"; f/7.2	P-B	1
P-B	Portable Reflectometer 2	0.4 - 12	0.375"; f/7.2	P-B	1
P-B	IPBR 1	0.4 - 12	0.125"; f/20	P-B	1
P-B	IPBR 2	0.4 - 12	0.125" to 1"; f/20	P-B	1
P-B	OPBR 1	0.4 - 12	0.25" to 1"; f/25	P-B	1

TABLE 5-32. OTHER PARAMETERS AND INFORMATION FOR THE REFLECTOMETER

Supplier	Model	Year Purchased/ Developed	Software Used	Calibrated with	Owner
Surface Optics	SOC-400T	n/a	n/a	n/a	P-1
Analytical Spectral Devices	Fieldspec-FR	n/a	n/a	n/a	P-1
P-B	Imaging Sphere	1986 - 1993	In-house propriety, ORACLE, OFFICE	Reference coupons	P-B
P-B	Imaging Sphere Environmental	1993 - 1996	In-house propriety, ORACLE, OFFICE	Reference coupons	P-B
P-B	Portable Reflectometer 1	1989 - 1991	In-house propriety, ORACLE, OFFICE	Reference coupons	P-B
P-B	Portable Reflectometer 2	1998 - 2000	In-house propriety, ORACLE, OFFICE	Reference coupons	P-B
P-B	IPBR 1	1986 - 1991	In-house propriety, ORACLE, OFFICE	Reference coupons	P-B
P-B	IPBR 2	1992 - 1993	In-house propriety, ORACLE, OFFICE	Reference coupons	P-B
P-B	OPBR 1	1996 - 2000	In-house propriety, ORACLE, OFFICE	Reference coupons	P-B

TABLE 5-33. COMMENTS ON THE REFLECTOMETERS

Supplier	Model	Comments	Owner
Surface Optics	SOC-400T	n/a	P-1
Analytical Spectral Devices	Fieldspec-FR	n/a	P-1
P-B	Imaging Sphere	Ambient samples, high LWIR precision (0.064%); DHR	P-B
P-B	Imaging Sphere Environmental	Heated samples (up to 700F); DHR	P-B
P-B	Portable Reflectometer 1	In-situ samples, vehicle surfaces; DHR	P-B
P-B	Portable Reflectometer 2	In-situ samples, vehicle surfaces; DHR	P-B
P-B	IPBR 1	Ambient samples, grazing incident/viewing, monostatic geometry, in-plane bidirectional	P-B
P-B	IPBR 2	Ambient samples, grazing incident/viewing, monostatic geometry, in-plane bidirectional	P-B
P-B	OPBR 1	Ambient samples, grazing incident/viewing, full hemispheric geometry, out-of-plane bidirectional	P-B

f. Other Types. Other types of instruments are listed in Table 5-34.

TABLE 5-34. OTHER TYPES OF INSTRUMENTS

Supplier	Radiometer Model	Spectral Range (μm)	Frame Rate (Hz)	Software	Year Purchased	Calibrated with	Comments	Owner	Qty (Unit)
-	Custom	0.77 - 1.2	Varies	Custom	2004	Other sources	NIR Suite containing Laboratory and Tactical systems	P-4	1
TI	TI	Other	Varies	Custom	2004	None needed	Tactical unit	P-4	1

CHAPTER 6

DRAFT DOCUMENT STANDARDS FOR CHARACTERIZING THE MEASUREMENT CAPABILITIES OF EO/IR MEASUREMENT SYSTEMS

This chapter is fundamentally based on a document entitled, *Draft of Electro-Optical Standard for Applications,* delivered 10 October 2006 to the SMSG-18 task lead, Mr. Jeffrey W. Burks (EO/IR Laboratory, Code SNS (now Code RYS) at the AFRL at Wright-Patterson AFB. The document was prepared under contract by EO/IR Remote Sensing Group, Mission Research and Technical Service Division, Alliant Techsystems Inc.

6.1 Executive Summary

6.1.1 Background. As part of the effort to serve the technical and operational needs of member test ranges and facilities, the RCC established the SMSG to develop signature measurement standards covering the electromagnetic spectrum. The SMSG focused on specific areas of radar, millimeter wave, infrared, laser, visible, ultraviolet, seismic, acoustic, and magnetic.

6.1.2 Scope. This draft documents standards for characterizing measurement capabilities of EO/IR measurement systems and helps establish a demonstration program that verifies and quantifies the improvement in measurement capability that will result from implementing documented standards. The standard will define levels of information contents that are synonymous with levels of knowledge and the requirements to meet these levels. For example, the lowest level would be capable of providing qualitative information. A middle level might provide relative quantitative information. The highest level incorporates both lower levels and could provide quantitative information with specified measurement uncertainties. The allowed levels are intended to specify cost-effective options to meet preset test requirements. The standard includes:

a. EO instrument characterization and calibration procedures.
b. Standard data reduction procedures to transform raw data to engineering units.
c. Measurement uncertainty analysis.
d. Standard terminology and units of measure.

This draft provides standards for planning, executing, and reporting signature measurements. It also describes the resources available to the IR range community and recommends procedures to help testers make efficient, effective use of instrumentation. Compliance with the standard and use of the recommended procedures will result in well-documented calibration and test data sets available to all users within the SMSG.

Following completion of the final product, new task proposals will be prepared at two, three, or four-year intervals to revise and update the standard. Conceivably, some of the standard will require frequent updates while others will require less frequent updates.

As part of the deliverables of the first year (and second year, if funded), the *Updated Objectives* will include a schedule for updates based on assessments of the applicable technologies at that time.

6.2 Overview

The following definition will be used throughout this document. *Electro-optical* (EO) refers to sensors and associated measurement systems used to characterize infrared through ultraviolet (25 micrometers to 0.2 micrometers) radiation. Measurement systems include optical components and photon-sensitive electronic digital detectors.

In this document, the EO standard for application is organized in three levels of knowledge with each level covering three to four categories:

a. Level I. Basic measurement capability for qualitative detection or bookkeeping.
b. Level II. Relative identification of general target characteristics For example, relative radiance or products derived from relative radiance such as relative spatial reflectivity and relative spatial temperature map.
c. Level III. Absolute measurement on specific target properties.

Common descriptors for all three levels include applicable techniques, instrumentation involved, experimental setup, operator qualification, cost factor, data acquisition, data analysis, and data report. Potential characteristics for all the levels are listed in Table 6-1.

TABLE 6-1. DESCRIPTORS VS LEVELS

No.	Descriptors	Level I	Level II	Level III
1	Spectral Band Choice	Important	Important	Important
2	Field of View (FOV)	Important	Important	Important
3	Detector Dynamic Range	Important	Important	Important
4	ADC requirement	low	medium	important
5	Signal Conditioning	Yes	Yes	Yes
6	Background correction	None	Some	Important
7	Data Acquisition	Yes	Yes	Yes
8	Data Processing	Minimum	Some	Important
9	Data Analysis	Yes	Yes	Yes
10	Data Reporting	Yes	Yes	Yes
11	Detector System Size and Weight	Consideration	Consideration	Consideration
12	DC Powered Option	Consideration	Consideration	Consideration
13	Cable Harness	Consideration	Consideration	Consideration
14	Environment Issues	Yes	Yes	Important
15	Relative Calibration (on-the-flight)	No	Yes	Yes
16	Absolute Calibration (traceable)	No	No	Yes
17	Uncertainty Analysis	No	Yes	Yes
18	Image Quality	low	medium	high
19	Field Test Potential	Yes	Yes	No
20	Setup or alignment requirement	Low	Medium	Higher
21	Operator Qualification	Intern Level	Junior Engineer	Senior Scientist
22	Overall Cost Factor	Low	Medium	Higher

6.2.1 Spectral Band. It is essential to select appropriate spectral band for a given application to optimize detection sensitivity, dynamic range, signal noise ratio, etc. However, situations do arise in which one needs to detect signals in a predefined spectral region where detection condition is not optimized (due to either the nature of the signal or the limitation imposed upon by instrumentation availability). In any case, the trade-off of spectral band selection is:

a. Spectral response
b. S/N ratio
c. Detector dynamic range
d. Image contrast
e. Cost

It is also critically important in the selection of windows, lenses, and detector after the spectral band and bandwidth are determined.

6.2.2 Field of View (FOV). For IR signature measurements, FOV requirement is decided by target size and the distance from the target to the sensor. On the other hand, the system FOV depends on the instrument configuration. Thus, it is important to estimate the required FOV for signal detection based on each specific application and then configure a sensor system that meets the FOV requirement. In case of IR imaging application, this involves selection of a camera lens that has appropriate focal length and f-number. The impact of instrument FOV is:

a. S/N ratio.
b. Spatial resolution (scanning).
c. Temporal or spatial dynamic range (moving target).
d. Cost.

6.2.3 Dynamic Range. Detector dynamic range will affect the following:

a. S/N ratio.
b. Image contrast.
c. Measurement accuracy.

6.2.4 ADC Requirement. ADC with better digital resolution is required for Level III knowledge in order to fully utilizing the potential of a higher end camera. The impact is:

a. Accuracy.
b. Resolution.
c. Cost.

6.2.5 Signal Conditioning. Depending on specific application, the signal conditioning required by radiometric sensors can be very diverse. It is important that the appropriate signal conditioning be used to fully realize the potential of a given sensor system.

For example, one of the important parameters associated with detector/preamplifier combination is the electric bandwidth which is defined as the range of frequencies within which the amplifier will respond. This frequency range is often measured between the half power (3-dB) points on the output response versus the frequency curve for a constant input. For various

reasons, the bandwidth of the signal electronics is often tailored by using electronic filters. For example, high and low pass electronic filters are often applied to remove the 60 Hz noise from the power grid and noise of frequencies outside the frequency band of interest.

It is also important that the gain and noise figure of the preamplifier be adequate to assure that the S/N ratio of the detector is not seriously degraded by the remainder of the system. The noise figure is defined as the ratio between the S/N of the input to an amplifier to the S/N at the output. Noise figures of near unity are desirable in the detector and amplifier, as are high sensitivities or gains in the first stage of a circuit. Noise becomes progressively less critical in amplifier stages with gains greater than unity added beyond the preamplifier.

Other common signal conditioning procedure includes the use of synchronous demodulation or phase sensitive detection (a type of correlation analysis). This procedure involves the use of a chopper-modulated signal with a lock-in amplifier to remove DC offset from the signal and to improve the S/N ratio of the sensor system.

6.2.6 Background Correction. Background correction is essential for Level III knowledge and includes the following:

a. Background object and atmosphere emission.
b. Background object and atmosphere transmission.
c. Background object and atmosphere reflection.

6.2.7 Data Acquisition. Data acquisition (DAQ) is the act of recording the signal in a form that is amenable to analysis. Common forms of DAQ are:

a. Voltage or current taken from various sensors during the course of an experiment.
b. Analog/Digital imageries taken with cameras.
c. X-Y plotters.
d. Microdensitometers.
e. Strip charts.
f. Analog tape recorders.
g. Digital data acquisition has become the standard and preferred form. Typical digital DAQ system contains a multiplexer, a sample and hold amplifier, an analog to digital converter (ADC), an interface to a central processing unit, high speed and bulk memory, and input/output (I/O) devices.

The important considerations for the multiplexer are its programmability, range of permissible voltages or dynamic range, and switching speed or multiplexer settling time; for the sample and hold amplifier, the acquisition and operative times along with their settling times. The acquisition time is the delay between the time the hold control signal is applied and the actual time the circuit enters the hold mode. The ADC may take many forms. Popular types are the integration, successive approximation, tracking, multi comparator ladder and voltage to frequency converters. The questions arising when applying ADC's are usually how rapidly and accurately are the conversions made. Information theory (by Shannon or Nyquist) suggests that the conversion should occur at a rate at least twice the maximum frequency of interest.

6.2.8 Data Processing. The signal recorded by the data acquisition system is retrieved and processed in some fashion to yield the final information desired from the measurement system. In general, data processing is synonymous with the digital DAQ process followed by computer aided data manipulation and graphic presentation of results. The data processing step might be as simple as the addition of units of measure on a strip chart or as complex as the digitization, scaling, and Fourier transformation, etc. to extract desired information. Data processing includes viewing the data as it is processed and archiving the data. Usually, data processing is minimum for Level I applications; some data processing is needed for Level II applications; extensive data processing is necessary for Level III applications.

Typical data processing steps include:

a. Conditioning of the analog signal to provide appropriate levels and bandwidths of signals for the digitizer.
b. Actual digitization of the data and the transfer to computer memory.
c. Storage of the data on bulk memory for later processing or reprocessing if required.
d. Retrieval and reformatting of the data for subsequent file manipulations.

6.2.9 Data Analysis. Data analysis is generally performed after the measurements. Immediate minimal data analysis should be accomplished along with the generation of data to establish error bonds and to identify anomalies with their causes, such as the effects due to known environment perturbations, instrument effects, etc.

6.2.10 Data Reporting.

a. Reporting contents for Level I knowledge are:
   (1) Image.
   (2) Date and time stamps.
   (3) Test notes (setup, instruments, environment).

b. For Level II knowledge, the contents include:
   (1) Images.
   (2) Numerical values.
   (3) Graphs.
   (4) Theoretic model used.
   (5) Measurement equation.
   (6) Test notes (setup, instruments, environment).

c. For Level III knowledge, the content reported includes the above for Level II knowledge as well as:
   (1) Calibration procedure and method.
   (2) Calibrations standard used.
   (3) Uncertainty analysis.
   (4) References used.

6.2.11 Detector Size and Weight. Important issue for field test applications.

6.2.12 DC Power Option. A consideration for all levels, depends on specific situation

6.2.13 Cable Harness. The cable harness is important for the following reasons:

a. Potential noise generation due to contact problem.
b. Minimize noise pickup by using well-shielded cables.
c. Minimize cable tension at detector to improve setup stability.

6.2.14 Environmental Issues. Environmental condition is vital to Level III knowledge since it will affect measurement accuracy and reproducibility.

6.2.15 Relative Calibration. Relative calibration provides a relative scaling factor to measurement result. Depending on the specific application, the calibration could be for sensor spectral, spatial, and temporal response with known sources; its linearity or nonlinearity for possible inputs must be determined; parameter such as FOV, frequency response, and the like must be known. For IR measurements, the calibration can be performed in any lab or on the flight during field tests against a thermally stable source with known spectral contents. In general, this type of calibration is also traceable to an absolute calibration. In this case, the output signal from a relatively calibrated sensor can be directly related to a transfer standard.

For example, calibration of a radiometer system with a linear response to input radiation requires a number of steps:

a. Determine calibration technique for in-band radiance, radiant intensity, and irradiance.
b. Determine instrument spectral characteristics.
c. Use known source to generate instrument output (voltage or current) signal.
d. Determine source output (for example, generate Planckian curves and geometry).
e. Repeat calibration steps at least twice.
f. Calculate the instrument response (for example, for a radiance calibration).

6.2.16 Absolute Calibration. This type of calibration is traceable to NIST standard and should be compliant with international standard. It provides absolute scaling to the measured result and need to be performed periodically in dedicated facilities. The standard calibrated against is accompanied with uncertainty analysis as well as signed and dated calibration certificate.

First, the calibration requirement is determined from the intended instrument application. Then, a suitable calibration source is positioned to either overfill or under-fill the FOV of the instrument, depending upon the type of calibration required. For example, absolute IR camera, IR radiometers, or IR spectrometer calibration involves measuring the emissivity of a blackbody cavity as a function of temperature, wavelength, distance, aperture size, FOV, etc. to determine the response of the instrument. In these IR calibrations, the known sources are Planckian radiators which behave nearly like blackbodies. The calibration source radiance is calculable, within an error band related to the accuracy of their measured temperature, emissivity, and uniformity, using the well-known Planck equation. In the case of a radiance calibration the source is situated nearby (possibly with an evacuated path to the sensor) to overfill the FOV of the instrument. The distance from the source to the instrument is not needed for further

calculations. For radiant intensity calibrations, the source is situated to under-fill the instrument FOV. In this type of calibration, the distance from the instrument to the source and the area of the source are required for subsequent calculations. Typically several sources, with varying temperatures, ranges, areas, FOVs, etc., are viewed and at least two measurements are required.

In general, signals are recorded with sources at two or more different known output conditions. A multiplicative instrument response is derived from these measurements, the output of the source for the two different conditions are determined from measurements (with standard detectors, manuals, calculations, etc.) and the difference is calculated. The difference between the signals recorded when exposed to the sources under two different conditions is then determined. The instrument response is the ratio of the two differences. For example, in one type of calibration, the instrument signal might be measured in volts and the source radiant output in watts per steradian within a specified spectral band. The multiplicative response would then be a number with units of watts per steradian per volt within the specified bandpass which could be used as a multiplier of voltages measure while viewing unknown sources to yield the inband radiant intensity attributable to the source.

Typical IR camera, radiometer, or spectrometer calibration includes the following steps:

a. Calculate radiances of the calibration sources using at least two different temperatures.
b. Find the transmission and reflection of the filters, windows (optical or atmospherical), lenses, mirrors etc.
c. Find the spectral response of the camera or radiometer.
d. Find the normalized product of the spectral transmission of the filters, windows, lenses, mirrors, detectors, etc.
e. Find the product of the source radiance and normalized transmission term.
f. Integrate the calculated spectral radiance/transmission product and measure the corresponding camera/radiometer voltage (Atmospheric effect may also be treated within this step).
g. Calculate the instrument response (i.e., the slope of the radiance vs. voltage function).
h. The radiance of the test target is then the product of the instrument response and the voltage measured while viewing the target.

6.2.17 Uncertainty Analysis. Uncertainty analysis is required for Level II and Level III applications. The methodology and arithmetic of uncertainty analysis is presented in numerous references and will not be discussed in this draft. The key to perform uncertainty analysis for radiometric instruments is to correctly identify and estimate the magnitude of error associated with each error source. The errors must also be classified as bias or precision. The elemental errors have to be summed up with appropriate mathematical scheme to determine the final uncertainty limit. Possible sources of error associated with radiometric instrumentation are:

a. The parameters related to the calibration source such as temperature, emissivity, and uniformity.
b. Geometry parameters such as the source to sensor distance, source area, instrument FOV.
c. The atmospheric transmission, reflection, and absorption.

d. The spectral characteristics of the detectors, filters, lenses, and windows.
e. The gain, bias, drift, linearity, frequency response, sensitivity, dynamic range, spatial and spectral resolution of the instrument and associated data acquisition system.

6.2.18 Image Quality. The purpose of measuring the quality of an image is to decide the usefulness of an image to a specific application and to evaluate the design or operation of an image system. The National Imagery Interpretability Rating Scale (NIIRS) defines and measures the quality of images and performance of an imaging system. The NIIRS criteria are based on textual descriptors to define the interpretability of an image at a specific NIIRS level. There are total of 55 NIIRS criteria for 10 levels. Six criteria are for each level from levels 1 through 9. A single criterion is at level 0 (the lowest level). Based on this scale, an image can be evaluated through a rating process. As the result, the given image is assigned a number (from 0 to 9) to indicate its interpretability. The higher the assigned number, the higher the imagery interpretability is. Because the NIIRS criteria are strongly based on spatial information, more information can be extracted from an image with a higher NIIRS rating. Thus, the NIIRS provides a systematic approach to measuring the quality of photographic or digital imagery, the performance of image capture devices, and the effects of image processing algorithms.

By referring to the NIIRS criteria, an example of progression in spatial detail for the application of target characterization is given in paragraph 6.9.

6.2.19 Field Test Potential. Level I and Level II measurements are applicable to field test or general laboratory conditions. Level III knowledge is usually meant for laboratory with environment controls for accurate and reproducible measurement. Depending on the specific application, Level III knowledge might also be pursued in open field. For example, if you are interested in the IR signature of a new boat on a calm open ocean at night it would be possible to measure with absolute calibrated and spatially corrected radiances that would qualify as a Level III measurement.

6.2.20 Setup or Alignment Requirement. Level I setup or alignment requires minimal effort; Level II fidelity require substantial effort in test setup and instrument alignment; Level III fidelity demands stringent setup or alignment conditions in order to reproduce accurate result.

6.2.21 Operator Qualification. It is assumed that the experiment or test setup is already finalized. Different levels of skills or experience are expected from an operator to collect data, processing data, and report data for different level of applications. In general, senior level scientists are always involved in the designing of the experiment setup to specific applications and in validating as well as in interpreting the measurement results.

6.2.22 Overall Cost Factor. Overall cost factor depends on specific aspects such as:

a. Level of fidelity.
b. Experiment complexity.
c. Experimental conditions.
d. Instrumentation requirement.
e. Operator education background and level of experience.

6.3 Level I Fidelity

6.3.1 Level I Fidelity Situations. Level I applies to the following situations:

a. For applications where qualitative results are sufficient.
b. For record keeping and photo documentary purposes.
c. For labs or sites where only basic instrumentations are available.

6.3.2 Level I Fidelity Information. Information for Level I includes but is not limited to:

a. Relative temperature distribution (contrast).
b. Relative geometry (shape and size).
c. Relative brightness (contrast).
d. Target material type (metal or non-metal).
e. Relative motion (against background).
f. Transient effect (flashes).

6.4 Level II Fidelity

6.4.1 Level II Fidelity Situations Level II fidelity is a mid step between Level I and Level III. Certain overlaps between the levels are expected, and Level II mainly applies to situations where qualitative results are not sufficient and approximate numerical values are needed. In Level II, relative calibration on instrument is required.

6.4.2 Level II Fidelity Information. Information sought for Level II fidelity might include the following:

a. Characteristic temperature (average, maximum, minimum).
b. Thermal conductivity (typical values).
c. Radiance (typical values).
d. Transmittance (typical values).
e. Reflectance (typical values).
f. Emissivity (typical values).
g. Surface roughness (typical values).
h. Polarization state (dominant component).
i. Spatial frequency (textures or patterns).
j. Physical properties (size and contour).

6.5 Level III Fidelity

6.5.1 Level III Fidelity Situations. Level III fidelity applies to applications where accurate, reliable, and reproducible numerical results are required. Absolute and traceable instrument calibrations are required for this level of fidelity.

6.5.2 Level II Fidelity Information. Information sought under Level III fidelity includes those sought under Level I and Level II fidelities as well as the following:

a. Absolute temperature distribution and gradient.
b. Absolute radiance.
c. Absolute emissivity.
d. Absolute reflectivity.
e. Absolute surface roughness.
f. Degree of polarization.
g. Field phase distribution.

6.6 Examples: Level I

6.6.1 Printed Circuit Board. Infrared thermal imaging can be used to measure steady state temperature distribution on a *printed circuit board* for trouble shooting or circuit diagnostics.

a. Close up lens with larger FOV.
b. Larger thermal dynamic range.
c. Manual NUC correction.
d. Real-time monochrome video signal output from camera.
e. Real-time image displaying.
f. Image storage medium.

6.6.2 Fire in Burning Building. LWIR or MWIR spectral band could be the choice. This application might require an IR camera with faster time constant in order to capture transient thermal effects such as flame with changing intensity and direction, etc. More often, an absolute surface temperature is desired in this situation to assess whether a victim should be rescued immediately, whether a door should be open, etc.

6.6.3 Deer on Road. LWIR (7-14 μm) camera would be the first choice for earlier detection of road hazards for vehicles traveling during night. The camera should increase a driver's night visibility three to five times the normal range of vehicle headlights. In the LWIR spectral region, thermal radiation dominates and energy emitted by objects would be function of their temperature and emissivity. Thus, the resulting video output would be a thermal map of the forward road scene where hotter objects appear brighter than cooler objects.

a. LWIR Camera.
b. Long focal length lens with smaller FOV.
c. Weight.
d. Environmental consideration.
e. Real-time monochrome video signal output from camera.
f. Higher thermal sensitivity.
g. Faster time response or shorter integration time.
h. Real-time video display.
i. Mounting bracket required.
j. Battery powered.
k. Able to operate in intended environment.

6.6.4 Airborne Surveillance. On the Level I, the majority of the airborne surveillance tasks would be of EO/IR imaging in down-looking mode. The imaging tasks include real-time or near real-time battlefield target recognition and tracking, facility monitoring, environmental observation, thermal plume detection, etc. Depending on the specific tasks, these applications might need a MWIR or LWIR camera. The general requirement for the instrumentation is compact with small footprint and light weight. The capability of measurement under all weather conditions, etc.

6.7 Examples: Level II

6.7.1 Target Surface Characterization. Target surface characterization includes measurements on surface emissivity, radiance, reflectance, transmittance, polarization effect, surface roughness, etc. These applications in general require cooled IR camera with appropriate optics such as spectral filters, neutral density filters, polarizers. The parameters measured are functions of angles, temperature, and wavelengths.

6.7.2 Chemical and Biological Warfare Agent Remote Sensing. Most molecules and organic compounds possess spectral features in the IR that can be used for their detection and identification. Thus, an IR camera and spectrometer with moderate resolution can be used to detect organic compound and plums that may be related to toxic gases, pollutants, chemical and biological warfare agents, drug manufacturing byproducts, volcanic eruption, etc.

6.8 Examples: Level III

6.8.1 IR Range Measurement. This example involves target characterization inside an environment chamber or range. The parameters measured include effective (spectrally weighted) target emissivity, reflectivity, and radiance. The experimental parameters are target temperature, target elevation and azimuth angles, zone temperatures of the IR range.

Target temperature control is realized by either running chilled coolant through its body or by heating up its temperature using embedded electrical heaters. The key requirement for target temperature control is to have uniform temperature distribution over the whole volume.

Liquid nitrogen cooled LWIR camera with appropriate spectral filters and a lens that defined a smaller FOV are used for the measurement. Two different blackbodies (NIST traceable) were used to absolutely calibrate the IR camera. Temperatures of the blackbody were chosen to encompass as much as possible the span in radiance coming from the potential target or sample to be measured under different environmental and viewing conditions.

Since the IR camera measures effective quantities, coefficients such as emissivity, reflectivity, and transmittance are converted into effective quantities. This is done by summing the product of the desired spectral quantity and the spectral responsivity of the sensor (including the effect of spectral responsivity of any filter or filters used), and then dividing the result by the sum of the spectral responsivity.

Measurements for target surface radiance are carried out in an environment chamber. The chamber can be used to simulate the IR energy an object would encounter in the atmosphere

at an altitude as high as 35000 feet. This is accomplished by heating or cooling five different zones inside the chamber. In the measurements, the environment chamber temperature zones are set to simulate a particular IR environment at 1000 or 5000 feet. For each zone, the temperatures are the chamber zone temperature which yields the minimum RMS difference between the simulated IR chamber radiance (simulated using BOXMATCH and Moderate Resolution Atmospheric Transmission (MODTRAN)) radiance for the viewing angles corresponding to a particular zone. Modeling is needed to compare with the measured results.

6.8.2 Bench Mark Thermal Target. In this example, the target surfaces are either flat or cylindrical. IR surface emissivity is measured with IR imagers. The assumption is that a single Lambertian source is giving rise to radiant power and that the power is being detected by a sensor some distance away from the source. The target temperature control is realized by either flowing coolant through its body or by heating up its body using embedded electrical heaters. Thermal modeling is needed to compare with the measurements.

6.9 Example: NIIRS Criterion

Based on the NIIRS criteria, an example of progression in spatial detail for target characterization is listed in the following Table:

TABLE 6-2. EXAMPLE CRITERION PER NIIRS LEVEL

Level	Examples for Target Characterization
0	Interpretability of the imagery is precluded by obscuration or very poor resolution*
1	Able to detect a medium-sized facility such as shipyard or a factory or a township
2	Able to detect individual target such as big buildings, large air fields, etc.
3	Able to detect moving targets along road or river
4	Identify target from mixed background scenes such as building, field, river, forest, etc.
5	Able to identify the type of the target such as a car, a ship, or an airplane, etc.
6	Able to identify the geometry or the shape or the body style of a target
7	Able to identify small features on target surface such as bolts or holes, etc.
8	Able to identify target surface structure details such as patterns or textures
9	Able to extract target surface roughness information

* As defined in MIL Standard 150A(1), the concept of being able to recognize three bars as a measure of image quality in terms of resolution.

Note that NIIRS criteria have accounted for all the following factors that impact image interpretability:

a. Image scale (such as photographic scale).
b. Distance between target and detector.
c. Signal noise ratio.
d. Imaging system characteristics such as the quality of the optics and the performance of the FPA detector.

e. Environmental conditions such as sun angle, atmospheric transmission and haze.
f. Other conditions such as film duplication process, video monitor quality, etc.

6.10 Common Instrumentation Nomenclature

Figures of merits, operating characteristics, and other constraints must be considered when matching detectors to specific applications. The following are some of common nomenclatures:

a. Responsivity (power, temporal, and spectral).
b. Noise equivalent power (NEP).
c. Detectivity.
d. Specific detectivity.
e. Noise equivalent irradiance.
f. Time constant.
g. Quantum efficiency.

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CHAPTER 7

DRAFT HANDBOOK FOR ELECTRO-OPTICAL (EO) MEASUREMENTS

This chapter, designed as a draft handbook, is fundamentally based on a document entitled, *Handbook of Electro-Optical Standard for Applications (EOSPA)*, delivered 23 April 2007 to the SMSG-18 task lead, Mr. Jeffrey W. Burks (EO/IR Laboratory, Code SNS (now Code RYS) at the Air Force Research Laboratory (at Wright-Patterson AFB. The document was prepared under contract by EO/IR Remote Sensing Group, Mission Research and Technical Service Division, Alliant Techsystems Inc. That deliverable document, and this report, is principally a narrative based on ANSI Z-540.1-1994 and adapted to the field of EO/IR measurements. The adaptation includes examples and narrative guidance for most of the evaluation criteria.

1 PART I: INTRODUCTION

As part of the RCC effort to serve the technical and operational needs of member test ranges or facilities, the SMSG was formed to document signature measurement standards across the electromagnetic spectrum, and specifically in the following areas: radar, millimeter wave, infrared, laser, visible, ultraviolet, seismic, acoustic, and magnetic. This handbook is based in part on RCC 804-01 and IRIG Standard RCC 802-98, *Tactical Missile Signatures Measurement Standard and Definitions*, and is intended to assist SMSG members in EO and infrared IR signature measurements by documenting standard procedures. The overall structure and languages used in the Handbook are in parallel with that in the *Handbook for the Interpretation and Application of ANSI/NCSL Z540-1-1994* (Reference 1.2a).

1.1 Scope

This handbook documents standards for characterizing the measurement capabilities of EO/IR measurement systems and helps establish a demonstration program that verifies and quantifies the improvement in measurement capability that will result from implementing documented standards.

The standards defined include:

a. Instrument characterization and calibration procedures.
b. Standard data reduction procedures to transform raw data to engineering units.
c. Measurement uncertainty analysis.
d. Standard terminology and units of measure.

This draft provides standard for planning, executing, and reporting signature measurements. It also describes the resources available to the IR range community and recommends procedures to help testers make efficient, effective use of instrumentation.

Compliance with the standard and use of the recommended procedures will result in well-documented calibration and test data sets available to all users within the SMSG Group.

1.2 References

a. Handbook for the Interpretation and Application of ANSI/NCSL Z540-1-1994.

b. The International vocabulary of basic and general terms in metrology (VIM).

c. ISO/IEC Guide 2: 1986, General terms and their definitions concerning standardization and related activities.

d. ISO/IEC Guide 25: 1990, General requirements for the competence of calibration and testing laboratories.

e. ISO Guide 30: 1981, Terms and definitions used in connection with reference materials.

f. ISO Guide 10012-1.

g. MIL-STD-45662A: 1988, Calibration Systems Requirement.

h. ISO 8402: 1986, Quality – Vocabulary.

i. ISO Guide to the expression of uncertainty in measurement.

1.3 Definitions Relevant definitions used in the Handbook are quoted in the following sections with notes.

1.3.1 Calibration. The set of operations which establish, under specified conditions, the relationship between values indicated by a measuring instrument or measuring system, and the corresponding standard or known values derived from the standard.

Note: (Reference 1.2b – paragraph 6.11, with note 4 added):

a. The result of a calibration permits the estimation of errors of indication of the measuring instrument, measuring system, or the assignment of values to marks on arbitrary scales.
b. A calibration may also determine other metrological properties.
c. The result of a calibration may be recorded in a document, sometimes called a calibration certificate or a calibration report.
d. The result of a calibration is sometimes expressed as a calibration factor, or as a series of calibration factors in the form of a calibration curve.

1.3.2 Calibration Certificate or Report. Document prepared that presents calibration results and other information relevant to a calibration (Reference 1.2c - 12.3, amended).

1.3.3 Calibration Method. Defined technical procedure for performing a calibration or verification (Reference 1.2d - 3.9, amended)

1.3.4 Certified Reference Material (CRM). A reference material one or more of whose property values are certified by a technically valid procedure, accompanied by or traceable to a certificate or other documentation which is issued by a certifying body (Reference 1.2e - 2.2).

1.3.5 Inter laboratory Comparisons. Organization, performance and evaluation of calibrations on the same or similar items by two or more laboratories in accordance with predetermined conditions (Reference 1.2c - 12.5)

1.3.6 International (Measurement) Standard. A standard recognized by an international agreement to serve internationally as the basis for fixing the value of all other standards of the quantity concerned (Reference 1.2b – paragraph 6.2).

1.3.7 Influence Quantity. A quantity which is not the subject of the measurement but which influences the value of the measurand or the indication of the measuring instrument (Reference 1.2b – paragraph 2.7, amended)

Examples: ambient temperature; pressure; humidity level; frequency of an alternating measured voltage.

1.3.8 Laboratory/Calibration Laboratory. Body that calibrates or performs calibrations and verifications

Notes (Reference 1.2d – paragraph 3.1, amended):
In cases where a laboratory forms part of an organization that carries out other activities besides calibration, the term "laboratory" refers only to those parts of that organization that are involved in the calibration process.
As used herein, the term "laboratory" refers to a body that carries out calibration at or from a permanent location, at or from a temporary facility, or in or from a mobile facility.

1.3.9 Limits of Permissible Error (of a Measuring Instrument). The extreme values of an error permitted by specifications, regulations, etc. for a given measuring instrument (Reference 1.2b – paragraph 5.2, with added note)

Note: This term is frequently referred to as "tolerance" in the United States.

1.3.10 Measurand. A quantity subjected to measurement (Reference 1.2b – paragraph 2.6, amended)

Note: As appropriate, this may be the "measured quantity" or the "quantity to be measured."

1.3.11 Measurement. The set of operations having the object of determining the value of a measurand (Reference 1.2b – paragraph 2.1, amended, without note).

1.3.12 Measurement Assurance. Measurement assurance is a technique that may include, but is not limited to:

a. Use of good experimental design principles so the entire measurement process, its components, and relevant influence factors can be well characterized, monitored and controlled;
b. Complete experimental characterization of the measurement process uncertainty including statistical variations, contributions from all known or suspected influence factors, imported uncertainties, and the propagation of uncertainties throughout the measurement process; and
c. Continuously monitoring the performance and state of statistical control of the measurement process with proven statistical process control techniques including the measurement of well characterized check standards along with the normal workload and the use of appropriate control charts.

1.3.13 Measurement Standard. A material measure, measuring instrument, reference material or system intended to define, realize, conserve or reproduce a unit or one or more known values of a quantity to serve as a reference (Reference 1.2b 6.1, without note).

1.3.14 Measuring and Test Equipment. All of the measuring instruments, measurement standards, reference materials, and auxiliary apparatus that are necessary to perform a measurement. This term includes measuring equipment used in the course of testing and inspection, as well as that used in calibration (Reference 1.2f – paragraph 3.2, amended).

Note: In the context of this Standard, the term "measuring and test equipment" is taken to encompass "measuring instruments" and "measurement standards". Moreover, a "reference material" is considered a type of "measurement standard".

1.3.15 Measuring Instrument. A device intended to make a measurement, alone or in conjunction with supplementary equipment (Reference 1.2b 4.1)

1.3.16 Mutual Consent Standard. An artifact or process that is used as a de facto standard by mutual consent of the supplier and customer when no recognized U.S. national standard is available (Reference 1.2g - 3.2, amended)

1.3.17 National (Measurement) Standard. A standard recognized by an official national decision to serve, in a country, as the basis for fixing the value of all other standards of the quantity concerned (Reference 1.2b – paragraph 6.3)

1.3.18 Proficiency Testing. Determination of the laboratory calibration performance by inter laboratory comparisons or other means (Reference 1.2c – paragraph 12.6, amended).

1.3.19 (Quality) Audit. A systematic and independent examination to determine whether quality activities and related results comply with planned arrangements and whether these arrangements

are implemented effectively and are suitable to achieve objectives (Reference 1.2h – paragraph 3.10, with note 1 only).

Note: The quality audit typically applies to, but is not limited to, a quality system or elements thereof, to processes, to products, or to services. Such an audit is often called a quality system audit, a process quality audit, a product quality audit, or a service quality audit.

1.3.20 Quality Manual. A document stating the quality policy, quality system and quality practices of an organization (Reference 1.2d – paragraph 3.10).

Note: The quality manual may call up other documentation relating to the laboratory's quality arrangements.

1.3.21 Quality System. The organizational structure, responsibilities, procedures, processes and resources for implementing quality management (Reference 1.2h -3.8, without notes)

1.3.22 (Quality System) Review. A formal evaluation by management of the status and adequacy of the quality system in relation to quality policy and new objectives resulting from changing circumstances (Reference 1.2h – paragraph 3.12)

1.3.23 Reference Material. A material or substance of which one or more properties are sufficiently well established to be used for the calibration of an apparatus, the assessment of a measurement method, or for assigning values to materials (Reference 1.2e – paragraph 2.17, amended, without notes)

1.3.24 Reference Standard. A standard, generally of the highest metrological quality available at a given location, from which measurements made at that location are derived (Reference 1.2b – paragraph 6.6).

1.3.25 Requirement. A translation of the needs into a set of individual quantified or descriptive specifications for the characteristics of an entity in order to enable its realization and examination (Reference 1.2d – paragraph 3.16)

1.3.26 Traceability. The property of a result of a measurement whereby it can be related to appropriate standards, generally national or international standards, through an unbroken chain of comparisons (Reference 1.2b – paragraph 6.10, amended).

1.3.27 Uncertainty of Measurement. Parameter, associated with the result of a measurement that characterizes the dispersion of the values that could reasonably be attributed to the measurand (Reference 1.2b – paragraph 3.9).

Notes:

a. The parameter may be, for example, a standard deviation (or a given multiple of it), or the half-width of an interval having a stated level of confidence.
b. Uncertainty of measurement comprises, in general, many components. Some of these components may be evaluated from the statistical distribution of the results of series of measurements and can be characterized by experimental standard deviations. The other components, which can also be characterized by standard deviations, are

evaluated from assumed probability distributions based on experience or other information.

c. It is understood that the result of the measurement is the best estimate of the value of the measurand, and that all components of uncertainty, including those arising from systematic effects, such as components associated with corrections and reference standards, contribute to the dispersion.

d. This definition is that of the "Guide to the Expression of Uncertainty in Measurement" in which its rationale is detailed.

1.3.28 Verification Evidence by calibration that specified requirements have been met (Reference 1.2d – paragraph 3.8, amended)

Notes:

a. In connection with the management of measuring equipment, verification provides a means for checking that the deviations between values indicated by a measuring instrument and corresponding known values are consistently smaller than the limits of permissible error defined in a standard, regulation or specification peculiar to the management of the measuring equipment.

b. The result of verification leads to a decision either to restore to service, or to perform adjustments, or to repair, or to downgrade, or to declare obsolete. In all cases, documentation of the verification performed is kept on the measuring instrument's individual record.

c. The term "verification" as defined in this Standard is frequently referred to as "calibration" in the United States.

1.3.29 Approved Signatory A person who is recognized by an accredited body as competent to sign accredited laboratory calibration reports (Reference 1.2c – paragraph 16.9, amended)

2 PART II: GENERAL REQUIREMENTS FOR THE COMPETENCE OF CALIBRATION LABORATORIES

The following discussions apply to calibration laboratories in the development and implementation of their quality system.

2.1 Laboratory Organization and Management

2.1.1 Legal Identity. The laboratory shall be legally identifiable. It shall be organized and shall operate in such a way that its permanent, temporary, and mobile facilities meet the requirements of EOSPA.

2.1.1.1 Interpretive Guidance. The laboratory is normally an established business or corporation, or an identifiable division of a business or corporation, which meets the applicable legal requirements of the governmental jurisdiction in which it conducts business. The management and organization of the laboratory should be structured to ensure that applicable facilities conform to this Standard. Legal identifiability may aid in addressing issues of

liability/accountability, uniqueness, composition/scope, and independence of operation. Legal identification may also aid in the prevention of misapplication of the Standard to parts of the organization which do not truly comply.

2.1.1.2 Example(s). A laboratory may be a department, division or subdivision of a business or corporation that supplies products or services in addition to, or other than, calibration services, or it may be a business or corporation whose sole activity is to provide calibration services. A laboratory may operate as a function within a department of the Federal Government, such as the Department of Energy or the Department of Defense, or it may be a Weights and Measures Laboratory of a state which is frequently found within the jurisdiction of the state's Department of Agriculture.

2.1.2 Managerial Staff. The laboratory shall have managerial staff with the authority and resources needed to discharge their duties.

2.1.2.1 Interpretive Guidance. Laboratory management needs the authority to plan, organize, direct and control to assure quality and protect integrity of results. Laboratory management needs the support of senior management in terms of budget, equipment, facilities, and people.

2.1.2.2 Example(s). Many organizations give the laboratory manager the authority to select laboratory personnel, measurement equipment, laboratory location, etc. as well as inputs to the budget process. Indicators such as increased backlog, missed delivery dates, excessive errors, etc., are often signs of inadequate resources and/or authority.

2.1.3 Personnel. The laboratory shall have arrangements to ensure that its personnel are free from any undue pressures that might adversely affect the quality of their work.

2.1.3.1 Interpretive Guidance. Laboratory personnel should be insulated from any work related pressures that would compromise the quality of work. The source of undue pressure may be internal due to management pressure, deadlines, etc. or external due to customer complaints, priority requests etc.

2.1.3.2 Example(s). Communications (priority requests, complaints, status inquiries, etc.) could be directed through supervision or administrative personnel. The existence of company ethics programs, skip-level management interviews, company ombudsman programs, etc. may also provide avenues of coordination that preclude adverse effects resulting from commercial pressures. An independent lab might use employee performance goals that are based more on the quality of work rather than the quantity.

2.1.4 Organization Structure. The laboratory shall be organized in such a way that confidence in its independence of judgment and integrity is maintained at all times.

2.1.4.1 Interpretive Guidance. Whether a laboratory operates as part of a larger organization, government agency, or as a stand-alone business, it should be operated so that quantity does not influence quality.

2.1.4.2 Example(s). A laboratory may organizationally report to the department responsible for quality of the delivered product rather than the production department.

2.1.5 Documentation. The laboratory shall specify and document the responsibility, authority, and interrelations of all personnel who manage, perform, or verify work influencing the quality of calibrations.

2.1.5.1 Interpretive Guidance. The laboratory should have an organization chart and job descriptions for the entire calibration laboratory. Responsibilities and authorities should be clearly defined.

2.1.5.2 Example(s). Job descriptions may be either general or detailed depending on the size, complexity, flexibility, and functions of the organization. The important issue is that all concerned parties must be able to understand the roles, responsibilities, and authorities associated with their assignments and that this information is documented.

2.1.6 Supervision. The laboratory shall provide supervision by persons familiar with the calibration methods and procedures, the objective of the calibration and the assessment of the results. Management practices shall be such as to ensure adequate supervision.

2.1.6.1 Interpretive Guidance. Individuals assigned direct supervisory responsibilities over laboratory personnel should be knowledgeable in the methods, practices and procedures of the calibrations being performed and of assessing calibration results. The responsibilities of these supervisory personnel should not be so extensive as to limit their effectiveness.

2.1.6.2 Example(s). The laboratory supervisor should have the necessary training/skills in related disciplines sufficient to understand the measurements being made, assess the results, and make decisions that affect the quality of the results.

2.1.7 Technical Manager. The laboratory shall have a technical manager (however named) who has overall responsibility for the technical operations.

2.1.7.1 Interpretive Guidance. There should be an individual designated whose job description includes the authority to make decisions regarding the technical (standard selection, calibration method selection, technical qualifications of personnel, etc.) aspects of laboratory operations.

2.1.7.2 Example(s). As one example, a laboratory might assign a senior engineer, senior technician, chief metrologist or similar title to the position of technical manager, having the responsibility for the technical validity of all aspects of laboratory operations. As another example, a laboratory might have a single person fill several roles, one of which is to serve as technical manager.

2.1.8 Quality Manager. The laboratory shall have a quality manager (however named) who has responsibility for the quality system and its implementation. The quality manager shall have direct access to the highest level of management at which decisions are taken on laboratory policy or resources, and to the technical manager. In some laboratories, the quality manager may also be the technical manager or deputy technical manager.

2.1.8.1 Interpretive Guidance. Responsibility for the quality system of the laboratory should be assigned to an individual who is free of pressures, which may conflict, with the quality of calibrations.

2.1.8.2 Example(s). In a larger organization, the quality manager might report to the manager/director of the Quality Assurance department or its equivalent. In a smaller independent laboratory, the quality manager might report to, or even be, the laboratory technical manager, president, or owner.

2.1.9 Designated Alternates. The laboratory shall designate alternates in case of absence of the technical or quality manager.

2.1.9.1 Interpretive Guidance. Individuals who have the required knowledge and expertise to assume the duties of the technical or quality manager should be assigned as alternates to provide continuity of operation during absences of the technical or quality manager.

2.1.9.2 Example(s). An organizational chart or other suitable documentation that identifies alternates for the technical and quality managers might be posted or otherwise made available.

2.1.10 Policy and Procedures. The laboratory shall have, where relevant, have documented policy and procedures to ensure the protection of customer's confidential information and proprietary rights.

2.1.10.1 Interpretive Guidance. A laboratory should identify any customer information or material that is considered confidential or proprietary and have appropriate policies and procedures in place to protect the customer's interest.

2.1.10.2 Example(s). Identification of the need to protect information should logically be a requirement of the contract (real or implied) between the laboratory and its customer(s).

2.1.11 Measurement Assurance Programs. The laboratory shall, where appropriate, participate in inter laboratory comparisons and proficiency testing programs.

2.1.11.1 Interpretive Guidance. Laboratories are encouraged to participate in measurement assurance programs (MAPs) or other types of inter comparison programs between laboratories which provide increased confidence in processes and procedures. The appropriateness of such programs may be determined by the laboratory and/or customer needs.

2.1.11.2 Example(s). Inter comparison type programs are useful and effective tools for evaluating uncertainties in many measurement processes. Such programs are especially appropriate when intrinsic standards are employed or where no traceability to a national standard is available. Where intrinsic standards are used, the laboratory should demonstrate by measurement assurance techniques, inter laboratory comparisons, or other suitable means, that its intrinsic standard measurement results are correlated with those of national or international standards. Where traceability to national standards is not applicable, the laboratory should provide evidence of correlation of results by participation in a suitable program of inter laboratory comparisons.

2.2 Quality System, Audit, and Review.

2.2.1 Quality System. The laboratory shall establish and maintain a quality system appropriate to the type, range and volume of calibration activities it undertakes. The elements of this system shall be documented. The quality documentation shall be available for use by the laboratory personnel. The laboratory shall define and document its policies and objectives for, and its commitment to, good laboratory practice and quality of calibration services. The laboratory management shall ensure that these policies and objectives are documented in a quality manual and communicated to, understood, and implemented by all laboratory personnel concerned. The quality manual shall be maintained current under the responsibility of the quality manager.

2.2.1.1 Interpretive Guidance. The laboratory should have a quality system documented in a quality manual that defines the policies and practices which must be followed in the conduct of its business. Laboratory management is responsible for ensuring that all laboratory personnel are aware of, understand, and implement the elements of the quality system. The quality manager is responsible for maintaining the quality manual.

2.2.2 Quality Manual. The quality manual and related documentation shall state the laboratory's policies and operational procedures established in order to meet the requirements of this Standard.

2.2.2.1 Interpretive Guidance. The phrase "quality manual and related documentation" is a direct reference to the quality documentation defined in paragraph 2.2.1 as being required to "be available for use by the laboratory personnel". The quality manual should contain "policies and objectives for, and commitment to, good laboratory practice and quality calibration services." These policies and objectives should reference the quality documentation containing the procedures and practices to be followed to ensure the policies and objectives are met. The quality manual and related documentation shall also contain the following list of subjects which should be addressed in the quality manual and related documentation:

1) A quality policy statement, including objectives, by top management, expressing the commitment to and intent of management and staff to provide sound and reliable services to its customers;
2) The organization and management structure of the laboratory, its place in any parent organization, related organization charts, outline, or description of the organizational structure of the laboratory and its location within a parent organization, if applicable, should be included. A chain of command should be established to identify responsibilities and personnel who have critical positions within the laboratory.
3) The relations between management, technical operations, support services and the quality system (A description of how the various organizational components of the laboratory interrelate to create a single cohesive laboratory program should be included).
4) Procedures for control and maintenance of documentation: The procedures, responsibilities, and authorities for drafting, changing, approving, and issuing documents needed for conducting the laboratory's business (procedures, drawings, schedules, work plans, job orders, test methods, etc.), including the quality

manual and related quality documentation, should be documented and referenced. The control of documents should ensure that:

a. Pertinent issues of appropriate documents are available at all locations where operations essential for the functioning of the quality system are performed.
b. Invalid and/or obsolete documents are promptly removed from all points of issue or use, or otherwise assured against unintended use.
c. Any obsolete documents retained for legal and/or knowledge-reservation purposes are suitably identified.

5) Job descriptions of key staff and reference to descriptions of other staff: Job descriptions of personnel in positions of responsibility; i.e., those who are empowered to make decisions should be included. Job descriptions of all other laboratory personnel, whose duties might affect the quality of the service provided, should be referenced as to where details might be found.
6) Identification of the approved signatories of the laboratory (where this concept is appropriate): An approved signatory is defined as an individual (not a position or job title) who is recognized by an accreditation body as competent to sign accredited laboratory test or calibration reports. Approved signatories should be persons with responsibility, authority and technical capability within the organization for the results produced. In selecting approved signatories, the following should be considered:
   a. Qualification and/or experience;
   b. Position in the staff structure (should be technical personnel closely involved in the day-to-day operations of the laboratory).
   c. Familiarity with the procedures and awareness of any limitations of these procedures.
   d. Ability to make critical evaluations of calibration results and a position in the staff structure which makes them responsible for the adequacy of results.
   e. Knowledge of quality assurance procedures employed in the laboratory and ability to take appropriate and effective corrective actions, when required. An approved signatory may be a person engaged by the laboratory as a consultant or in a similar capacity as long as all requirements for competency are met.

Note: Paragraph 6 above only applies to accredited laboratories. Non-accredited laboratories wishing to be compliant with this Standard should internally designate approved signatories, following the same guidelines for selection.

7) The laboratory's procedures for achieving traceability of measurements: Reference to the methods and procedures used to establish the traceability path, to a national laboratory, an intrinsic standard or other acceptable source, should be included.
8) The laboratory's scope of calibrations and/or verifications: The laboratory's scope of calibrations describes the measurement and/or calibration capabilities of the service it provides.
9) Arrangements for ensuring that the laboratory reviews all new work to ensure that it has the appropriate facilities and resources before commencing such work: The quality documentation should contain procedures which ensure the laboratory has

the personnel, facilities, equipment, standards, and technical expertise necessary to handle proposed work effectively before it is accepted. Particular attention should be paid to work of a type not currently being performed in the laboratory. Consideration should be given to:

a. The scope of calibrations normally performed.
b. Available resources including equipment, staff, and space.
c. Workload.

10) Reference to the calibration and verification procedures used: Calibration/verification procedures are documented in accordance with the standard and are considered part of the quality documentation of a laboratory. Reference to these procedures should be made.
11) Procedures for handling calibration and verification items: Calibration and verification items refers primarily to customer equipment or "device under test", that is, equipment undergoing calibration/verification. Requirements for documentation of these procedures are defined in the Standard and should be referenced.
12) Reference to the major equipment and reference measurement standards used: A general description of the measurement systems and measurement standards used by the laboratory should be included. This provides information related to the laboratory's scope of calibrations and method(s) of achieving traceability. Detailed requirements for the care and usage of laboratory equipment are addressed in the Standard.
13) Reference to procedures for calibration, verification and maintenance of equipment used: "Equipment used" refers to all laboratory equipment (owned, rented or leased) having an effect on the results of the calibration services provided. Detailed requirements for the care of laboratory equipment are in the Standard.
14) Reference to quality assurance practices including inter laboratory comparisons, proficiency-testing programs, use of reference materials, and internal quality control schemes. Quality assurance practices are used to:
    a. determine agreements between laboratories.
    b. demonstrate compliance to certain specifications.
    c. indicate that the measurement processes are under statistical control.
    d. demonstrate traceability.
    e. ensure the quality of results.

    Details of using QA practices and requirements are in the Standard.
15) Procedures for feedback and corrective action whenever measurement discrepancies are detected, or departures from documented policies and procedures occur: Policies and procedures should describe the actions to be taken when it is discovered that an error has occurred or procedures were not followed. An assessment of the impact (of the discrepancy or departure) on the results of measurements and a determination of appropriate corrective action should be conducted. This requirement pertains to discrepancies or unplanned departures from normal operation.
16) The laboratory management arrangements for exceptionally permitting departures from documented policies and procedures or from standard specifications:

Laboratory management is responsible for ensuring that laboratory policies and procedures are followed. The quality documentation should include the required process to be followed when departing from these policies and procedures.

17) Procedures for dealing with complaints: A section of the Standard contains the requirements for dealing with complaints. These policies and procedures should be included in the quality documentation.
18) Procedures for protecting confidentiality and proprietary rights: The laboratory's procedures for identifying and protecting any customer information or material considered confidential or proprietary should be included in the quality documentation.
19) Procedures for audit and review: An audit is a detailed evaluation of the compliance with the quality system. It attempts to find out if the system is in fact working the way it is documented. A review is a comparison of the system with the general standard, other quality needs, and the general business of the laboratory to determine if something needs to be changed in the system which will end up with new or revised documentation. These are separate functions and must be treated separately by the laboratory. Requirements for audit and review procedures are defined in the Standard and should be included in the quality documentation.
20) A statement of the lab's policy for establishing and changing calibration intervals for equipment it controls: A section of the Standard specifies the requirements for establishing calibration intervals. These procedures should be included in the quality documentation.
21) A statement of the laboratory's policy concerning the technique(s) to be used for determining measurement uncertainty and calibration/verification adequacy: A section of the Standard covers the requirements for determining measurement uncertainty and calibration/verification adequacy. A policy statement referencing these procedures should be included in the quality documentation.

2.2.2.2 Example(s).

2.2.2.2.1 The relation between management, technical operations, support services and the quality system. Flow charts or written descriptions of work processes defining the responsibilities of and demonstrating interactions between the various organizational units might be provided.

2.2.2.2.2 Job Descriptions of key staff and reference to descriptions of other staff. Key personnel might be defined as Manager(s), Authorized Representative(s), Approved signatory(s), quality manager, senior metrologist, senior engineer, and others. Other staff might include engineers, technicians, administrative support personnel, and shipping and handling personnel.

2.2.2.2.3 The laboratory's scope of calibrations and/or verifications. An effective method of reporting a laboratory's capabilities is in a spreadsheet format. Citing a basic measurement discipline (MWIR or LWIR) and then the various sub-parameters under that specific discipline (radiometric, spectral responsivity, emissivity, etc.). Other information provided in this spreadsheet may include the range, accuracy and/or uncertainty, technique or method of calibration, and various remarks specific to the sub -parameter.

2.2.2.2.4 Reference to the calibration and verification procedures used. A laboratory's quality manual might reference calibration procedures as follows: "All calibrations conducted by this laboratory are performed in accordance with approved calibration procedures. Development and/or selection of procedures are based on suitability for purpose and customer requirements. All procedures are developed or selected and approved for use in accordance with guidelines found in Operational Procedure #XXX, "Calibration Procedure Selection and Development". Procedures are controlled documents with the designated approval signature(s) and issue date in accordance with Operational Procedure #ZZZ: "Document Control."

2.2.2.2.5 The laboratory management arrangements for exceptionally permitting departures from documented policies and procedures or from standard specifications. An example of a statement concerning deviation from established policies and the quality manual might be as follows: Any deviations from the guidelines in this document (quality manual) shall be described with supporting justification and shall have prior approval from the Calibration Laboratory Senior Management. Individuals desiring deviation from the requirements set forth in this document (quality manual) shall provide to the Calibration Metrology Management or designee prior to implementation a detailed description and justification for the proposed deviations for review. A complete description, justification, and record of approval shall be documented and maintained for history.

2.2.2.2.6 Procedures for protecting confidentiality and proprietary rights. Details of these procedures may be incorporated into the procedures for reviewing new work and/or handling of calibration items.

2.2.3 Quality Audit. The laboratory shall arrange for audits of its activities at appropriate intervals to verify that its operations continue to comply with the requirements of the quality system. Such audits shall be carried out whenever possible by trained and qualified staff who are independent of the activity to be audited. When the audit findings cast doubt on the correctness of validity of the laboratory's calibrations results, the laboratory shall take immediate corrective action and shall immediately notify, in writing, any client whose work may have been affected.

2.2.3.1 Interpretive Guidance. A quality audit is a periodic check to ensure that the laboratory is operating in accordance with the policies and procedures set out in the quality manual and related documentation. Quality audits may include audits of results. Audit intervals should be based on an analysis of factors such as risk, criticality of the measurement system, complexity of the system, and failure rates and may be different for each measurement area. Audits should be conducted by persons possessing the knowledge and skills necessary to understand the process being audited as well as the process of auditing. Auditors are preferably persons from outside the area being audited. Immediate corrective action refers to the speed and breadth of response necessary to prevent the taking of bad data and/or the generation of inaccurate results.

2.2.3.2 Example(s). The quality manager may be responsible for ensuring that all components of the laboratory's activities are audited. The task of carrying out audits may be

delegated to other staff with sufficient technical knowledge and appropriate auditing training. The audit process might include:

1) A planned schedule for the audits covering all quality activities at all sites over a specified period of time.
2) Audits conducted by someone independent of the activity concerned (wherever possible).
3) Documented audit procedures.
4) Recording of audit results.
5) Effective corrective action, undertaken within a reasonable and agreed upon timeframe, on all non-conformances identified within the quality system.

Each aspect of the quality system should be periodically audited at an appropriate interval to provide sufficient data for an effective management review. Many organizations find that an interval of six or twelve months to be appropriate.

2.2.4 Quality System Review. The quality system adopted to satisfy the requirements of this Standard shall be reviewed at least once a year by the management to ensure its continuing suitability and effectiveness and to introduce any necessary changes or improvements.

2.2.4.1 Interpretive Guidance. A quality system review is an examination of the entire quality system conducted by management to ensure that it is adequate for the achievement of the laboratory's quality objectives on a continuous basis.

2.2.4.2 Example(s). The quality manager, under direction of laboratory management, might be responsible for ensuring that all reviews are done systematically, according to a documented procedure, that results of revisions are recorded and that all actions resulting from the review are implemented within the specified time. The review could include at least the following:

1) Matters arising from the previous review.
2) Reports from audits by clients (if applicable).
3) Results of internal audits done since the last review, including corrective actions implemented.
4) Results of in-house quality checks.
5) Details of any complaints from clients.
6) Staff training (for both new and existing staff members).
7) Adequacy of staff, equipment and facility resources.
8) Future plans and estimates for new work, new staff, new equipment, etc.

Management may delegate the responsibility of scheduling the reviews to the quality manager or other appropriate individuals.

2.2.5 Documentation. All audit and review findings and any corrective actions that arise from them shall be documented. The person responsible for quality shall ensure that these actions are discharged within the agreed timeframe.

2.2.5.1 Interpretive Guidance. Documentation should be maintained, in a form suitable for assessment, of all audits and management reviews of the quality system and resulting corrective

actions (if any). Corrective action is required whenever evidence arises that the quality system is not functioning properly. The person responsible for quality is designated by laboratory management and is normally the quality manager.

2.2.6 Quality Check. In addition to periodic audits, the laboratory shall ensure the quality of results provided to customers by implementing checks. These checks shall be reviewed and shall include, as appropriate, but not be limited to the following:

1) Internal quality control using, wherever possible, statistical techniques. Measurement assurance techniques are acceptable means to control the measurement process and consistently produce the highest quality measurements.
2) Participation in proficiency testing or other inter laboratory comparisons.
3) Regular use of certified reference materials and/or in-house quality control using reference materials.
4) Replicate measurements using the same or different methods.
5) Correlation of results for different characteristics of an item.

2.2.6.1 Interpretive Guidance. Internal quality control programs are an integral part of any calibration laboratory program. The extent and detail of the program may vary based on the size and complexity of the laboratory's range of calibrations.

2.2.6.2 Example(s). Laboratories maintaining primary standards such as standard or items may wish to develop detailed statistical process control charts for the items utilizing check standards. For laboratories of lesser measurement capabilities (larger uncertainties), internal random sampling schemes may be incorporated whereby random items of instruments whose calibrations are completed are recalibrated by separate laboratory personnel. These sampling schemes may be based on a percentage of instruments calibrated where the percentage may be increased or decreased based on the number of failed inspections.

Internal quality control methods such as these are a few of the methods that may be used to provide statistical data supporting the credibility of the calibration laboratory "production" and the reliability and stability of laboratory standards.

When internal quality assurance and quality control techniques are not implemented, decreases in laboratory calibration quality may not be identified until long after detrimental effects to quality have occurred. This could cast significant doubt on the measurement system, the validity of calibrations performed by the laboratory and all measurements and measurement data collected utilizing the calibrated equipment.

2.3 Personnel

2.3.1 Staff Size. The calibration laboratory shall have sufficient personnel with the necessary education, training, technical knowledge and experience for their assigned functions.

2.3.1.1 Interpretive Guidance. The laboratory should maintain a staff of sufficient size so as not to cause unnecessary delays in the service it provides to its customers. Staff members should possess, at a minimum, the training and skills necessary to perform their assigned duties. Training should be "fit for purpose".

2.3.1.2 Example(s). Several schemes are available for monitoring the timeliness of the service provided by the laboratory, usually taking the form of a workload, or backlog, tracking system. Data collected from these types of systems may be used to evaluate whether or not the laboratory is providing the "speed" of service to its customers sufficient to satisfy their needs. Any such system employed need only be as complex as deemed necessary by laboratory management to suit its particular needs, so long as enough information is collected on which to base a determination. Training requirements might be established by first identifying the duties of each staff member, either individually or by job classification (supported by written job descriptions), and then determining the training and/or level of expertise required to perform these duties. Training should be, at a minimum, "fit for purpose". For example, if a technician is responsible for performing a statistical analysis of data collected during the calibration process, then he/she should possess the necessary skills to perform such an evaluation. These skills may be obtained from a variety of sources, such as formal education, formal training, on the job training, or any other suitable means. Some laboratories may also require their staff to demonstrate their competency by a variety of methods such as qualification testing, performance testing, ongoing proficiency audits, or review of results of laboratory proficiency tests.

2.3.2 Staff Training. The calibration laboratory shall ensure that the training of its personnel is kept up-to-date consistent with employee assignments and development.

2.3.2.1 Interpretive Guidance. The laboratory should have procedures for updating and/or augmenting the training of its staff as requirements change. These procedures should include provisions for recognizing when changes that may require training occur and how that training might be accomplished.

2.3.2.2 Example(s). Changes may occur for a variety of reasons, such as, but not limited to, reassignment of duties, new work taken on by the laboratory, changes in technology, updated methods and procedures, cross training of personnel and employee development. Job descriptions and associated training requirements might be periodically reviewed and modified as necessary to maintain compatibility with current measurement technology and to remain consistent with the laboratory's mission.

2.3.3 Staff Records. Records on the relevant qualifications, training, skills and experience of the technical personnel shall be maintained and be available to the laboratory.

2.3.3.1 Interpretive Guidance. A current listing of technical personnel and their relevant skills, work experience, formal education, technical training, on-the-job training, technical

license, certifications, and degrees should be maintained. All such information should be available to laboratory management.

2.3.3.2 Example(s). The documentation may be a controlled computerized list generated by the training department, personnel office, laboratory supervisor or, simply a collection of documents contained in the employees personnel file. The listing should be periodically reviewed by the employee and laboratory management to ensure accuracy and completeness.

2.4 Accommodation and Environment

2.4.1 Laboratory Environmental Conditions. Laboratory accommodation (facilities), calibration areas, energy sources, lighting, temperature, humidity, and ventilation shall be such as to facilitate proper performance of calibrations/verifications.

2.4.1.1 Interpretative Guidance. Environmental conditions should be appropriate for the type of work being performed. Calibration/verification requirements should be evaluated to determine which environmental factors have an impact. Only the environmental factors which could affect the accuracy, stability, or performance of the calibration require control. Human factors such as lighting and ventilation should be sufficient to perform the required tasks.

2.4.1.2 Example(s). The temperature control requirements for the calibration of an infrared detector would be tighter than the requirements for the calibration of other general-purpose equipment, which has a wide temperature operating range.

2.4.2 Experiment Environmental Conditions. The environment in which these activities are undertaken shall be specified and not invalidate the results or adversely affect the required uncertainty of measurement. Particular care shall be taken when such activities are undertaken at sites other than the permanent laboratory premises.

2.4.2.1 Interpretative Guidance. Environmental influence factors which affect the specific measurement being performed should be understood, documented and controlled to the degree necessary to avoid invalidating the calibration results or adversely affecting the required measurement uncertainty. These requirements also apply to off-site calibration in that care should be taken to monitor, record, and compensate for environmental factors which could adversely affect the measurement and/or its uncertainty. In an environmentally controlled area, an out of tolerance environmental parameter may not affect the required uncertainty.

Correction factors may be applied to compensate for the out of tolerance condition, thus allowing some work to continue.

2.4.3 Monitor, Control, and Record. The laboratory shall effectively monitor, control and record environmental conditions as appropriate. Due attention shall be paid, for example, to biological sterility, dust, electromagnetic interference, humidity, line voltage, temperature, and sound and vibration levels, as appropriate to the calibrations concerned.

2.4.3.1 Example(s). In an infrared calibration laboratory, temperature is critical and should be monitored, controlled, and recorded. Dust levels are also critical when making optical measurements. Humidity should be controlled so as to prevent corrosion of standards.

2.4.4 Sub Zoning. There shall be effective separation between neighboring areas when the activities therein are incompatible.

2.4.4.1 Interpretative Guidance. Activities in neighboring areas may have an adverse affect on the calibrations/verifications in another area. If activities are incompatible, they should be effectively separated by shielding or isolated by distance.

2.4.4.2 Example(s). Line voltage surges may be caused by motors or other high current drawing industrial equipment in neighboring areas. Line conditioners or regulated power sources should be employed to protect sensitive electronic equipment.

2.4.5 Access Control. Access to and use of all areas affecting the quality of these activities shall be defined and controlled.

2.4.5.1 Interpretative Guidance. Uncontrolled access to environmentally controlled areas may have an adverse affect on the quality of the measurements being performed. Areas where this potential exists should be identified and procedures should be established to control access.

2.4.5.2 Example(s). Unqualified personnel could unknowingly cause damage to calibration equipment or adjust calibration settings. Access to areas could be controlled by physical locks, security guards or other security access systems.

The number of personnel entering an environmentally controlled area should be limited. The more personnel entering the area the more dust and dirt will be introduced. If too many people are in the laboratory, their body heat could raise the temperature to an out-of-tolerance level.

Air lock systems can be used to help minimize the effects on temperature control when personnel enter an environmentally controlled area.

Electrostatic discharge workstations and special procedures should be used when working with some sensitive electronic equipment.

2.4.6 Housekeeping. Adequate measures shall be taken to ensure good housekeeping in the laboratory. It is the laboratory's responsibility to comply with the relevant health, safety, and environmental requirements. This aspect, however, is outside the scope of this Standard.

2.4.6.1 Interpretative Guidance. Poor housekeeping practices may have a negative impact on the quality of the calibrations/verifications being performed. Good housekeeping factors such as cleanliness, storage and space should be adequately controlled.

2.4.6.2 Example(s). Improper storage could cause damage to or degrade the accuracy of standards and measuring equipment. Some examples of improper storage are:

1) Stacking equipment too high.
2) Outside storage exposing equipment to the elements.
3) Storage in areas which exceed storage specifications.
4) Equipment not properly stored or secured after use.

Cleanliness of work areas and calibration equipment is critical when making precision measurements. A particle of dust or dirt could invalidate the calibration results.

Improper document storage could result in the loss of valuable quality records. Record files should be properly maintained and computer disks stored away from electromagnetic sources.

Filters on optical measurement equipment should be kept clean.

Improper storage of reference materials could affect their reliability or accuracy.

Improper maintenance of lighting fixtures, such as failure to replace light bulbs, could cause lighting levels to drop to unacceptable levels.

2.5 Equipment and Reference Materials

2.5.1 Equipment Availability. The laboratory shall be furnished with all items of equipment (including reference materials) required for the correct performance of calibrations/verifications. In those cases where the laboratory needs to use equipment outside its permanent control, it shall ensure that the relevant requirements of this Standard are met.

2.5.1.1 Interpretive Guidance. Laboratories should have available all equipment needed for the calibrations they normally perform, whether owned, leased, rented, or borrowed. The calibration laboratory should assure that leased, rented or borrowed equipment meets the requirements of this Standard. Noncompliance with this requirement could lead to partial calibrations, or calibrations using equipment of unknown integrity.

2.5.1.2 Example(s). Calibration laboratory "A" must rent a spectrometer in order to complete a calibration. "A" does not have the capability to verify the performance of the spectrometer and must rely on the rental company's calibration certification/sticker. Before using the spectrometer, "A" should have on file or obtain objective evidence that the calibration was performed in a manner which meets the requirements of this Standard.

Examples of objective evidence may be:

1) Records of your own audits.
2) Proof that the rental company's calibration laboratory is accredited against this Standard.
3) Acceptance of the rental company's calibrations by a government agency showing compliance to this Standard.
4) Acceptance conforming to this Standard from the calibration laboratory's customer.

2.5.2 Equipment Maintenance. All equipment shall be properly maintained. Maintenance procedures shall be documented. Any item of the equipment which has been subjected to overloading or mishandling, or which gives suspect results, or has been shown by verification or otherwise to be defective, shall be taken out of service, clearly identified and wherever possible stored at a specified place until it has been repaired and shown by calibration or verification to perform satisfactorily. The laboratory shall examine the effect of this defect on previous calibrations.

2.5.2.1 Interpretive Guidance. Maintenance of a calibration laboratory's equipment should be controlled. A calibration laboratory should have procedures describing how it maintains and controls equipment used to perform calibrations under this Standard. These procedures should state in detail:

1) How historical maintenance information is kept.
2) How an instrument that has been subjected to any influence that might cause doubt as to its integrity is handled.
3) How out of service equipment is marked.
4) How effects on previous calibrations are determined.
5) How operational status is identified.
6) Specifically where equipment is to be kept while out of service.

Failure to comply with this requirement could cause a technician to use defective equipment unknowingly in the process of calibration.

2.5.3 Equipment Labels. Each item of equipment including reference material shall, when appropriate, be labeled, marked, or otherwise identified to indicate its calibration status.

2.5.3.1 Interpretive Guidance. Any item that may be used in the calibration process should have evidence of its calibration and service status. If an item can be or might be used as a test standard, it should be marked such that a user can easily determine its calibration status. This prevents use of an item which may not be calibrated, may be defective, or may have an expired calibration date. Reference materials should be treated in a manner similar to equipment and have their current status identified in a manner that will allow a user to determine their validity. Typical identification of status is through the use of calibration labels, indicating the type of calibration (limited, special, see report etc.) and calibration due date. However, other schemes, such as computer systems keyed on instrument serial numbers, would be acceptable as long as the process is well documented and understood by all potential users.

2.5.3.2 Example(s).

1) "Calibration Labels" should be applied to equipment when its accuracy significantly affects the integrity of the measurement process.
2) If calibration labels cannot be applied (gage blocks, weights, small items, etc.) the information may be placed on the equipment container.
3) Local policies and procedures should clearly instruct all equipment users that an instrument is only considered useable for a calibration if a valid and current "label" (or other acceptable means of identification) is available.

2.5.4 Equipment Records. Records shall be maintained of each item of equipment and all reference materials significant to the calibrations/verifications performed. The records shall include:

a. The name of the item of equipment.
b. The manufacturer's name, type identification, and serial number or other unique identification.
c. Current location, where appropriate.
d. Where applicable, dates and results of calibration and/or verifications and date or criteria when the calibration and/or verification expires.
e. Details of maintenance carried out to date and planned for the future.
f. History of any damage, malfunction, modification or repair.
g. Measured value observed for each parameter found to be out of tolerance during calibration/verification.

2.5.4.1 Interpretive Guidance. The laboratory should keep historical files of calibrations of all laboratory equipment significant to the calibration process, containing sufficient information to prove calibration credibility at the time of each use. This includes documented measured

value data of any parameter found to be out of tolerance during initial verification, but does not require that data be kept on all parameters measured and found to be in tolerance.

2.5.4.2 Example(s).

1) Model: Model xxx.
2) S/N: xxx-xx-xx.
3) Name/Type: Blackbody.
4) Manufacturer: Any Corporation.
5) Location: 3975 5th Street.
6) Last Cal: November 17, 2006 Condition: REPAIR required.
7) Next Cal: November 17, 2007.
8) Maintenance History: 1/20/2004 received new.
9) 11/17/93 Temperature control failed; repaired and installed reliability upgrades; calibrated.
10) Reading history: (See calibration certificate/report).

2.6 Measurement Traceability and Calibration

2.6.1 Calibration System. All measuring/testing equipment having an effect on the accuracy or validity of calibrations shall be calibrated and/or verified before being put into service. The laboratory shall have an established program for the calibration and verification of its measuring and test equipment to ensure the recall or removal from service of any standard or equipment which has exceeded its calibration interval or is otherwise judged to be unreliable.

2.6.1.1 Interpretive Guidance. A calibration laboratory should have a calibration system for all equipment utilized in the calibration laboratory. This system should allow for:

1) Identification of equipment requiring calibration.
2) Identification of overdue items in the recall system and removal of such items until corrected.
3) Items that are known to be broken, out of tolerance, unstable so that its parameters cannot be predicted, or have intermittent problems, etc., or are judged unreliable, are identified and segregated until appropriate corrective action has been taken.

Corrective action may be in the form of limited use, repair, or correction factors, etc.

2.6.1.2 Example(s). There are usually two distinct groups of instruments involved in any calibration system:

1) Those that belong to or are assigned to the calibration laboratory itself. The calibration laboratory should keep tight control of all its equipment used for calibration. This includes periodic recalibration of its instruments/tools in most cases. Exceptions should be listed and identified as such.
2) Those that belong to or are assigned to customers of the calibration laboratory or that are maintained through an instrument pool or lease/rental program. Control of these instruments/tools is usually left to the user or its assigned delegate. It is

up to the user to identify items requiring periodic recalibration, to provide adequate identification, and maintain a tracking program for his equipment.

The calibration laboratory should have complete control of its inventory of instruments and tools used for the calibration and verification of its own items. These instruments/tools, utilized by the calibration laboratory, could be owned, borrowed, leased, or rented from other facilities or signed out from loan pools. In all cases, those items requiring calibration or verification should be fully accounted for at all times and should be in a calibrated/verified status through the use of an official calibration recall system.

It is important to note that not ALL instruments/tools used by the calibration laboratory for calibration or verification do require such actions. The calibration laboratory decides which items are used as sources or indicators, thereby requiring no calibration, and which items have an effect on the accuracy for the units under test.

A recall system will mean different things for different organizations, facilities, or agencies. In general, it can be said, however, that a recall system should include:

1) Identification of items requiring calibration or verification.
2) A detailed database for items requiring ca libration or verification that indicates past and future calibration dates, etc.
3) A description of how the instruments/tools requiring calibration and verification are moved to and from different calibration laboratories, how they are calibrated or verified including what procedures are used, and how calibration records are kept.

The recall system, through its database, should provide a means for identifying calibration laboratory items that are overdue for calibration. The calibration laboratory should ensure that such items are taken out of service and segregated until recalibrated.

Problem items such as repeated out-of-tolerance conditions of the same parameter of the same unit should be investigated for cause and possible problems downstream. Appropriate action should be taken by the laboratory to repair, derate, or eliminate such units from the inventory. A mechanism should be available to identify these items. Items that show abnormal behavior should be temporarily removed from the active inventory until the problems have been clearly identified and can be controlled.

Items that are broken should be removed from the active inventory and identified as such. Items for which trend and control charts are kept and which indicate that certain parameters are falling outside the predicted control limits, should be removed from the active inventory list, identified as such, and investigated for cause. Once understood and corrected they can be entered into the active inventory once again after adequate calibration.

2.6.2 Calibration Traceability. The overall program of calibration and/or verification of equipment shall be designed and operated so as to ensure that, wherever applicable, measurements made by the laboratory are traceable to national, international, or intrinsic standards of measurements where available. Calibration certificate and/or report shall, wherever

applicable, state the traceability to national, international, or intrinsic standards of measurements and shall provide the measurement results and associated uncertainty of measurement and/or a statement of compliance with an identified metrological specification.

2.6.2.1 Interpretive Guidance. In order to ensure adequate calibration quality, all calibration laboratory items in the recall system should be traceable to national or international laboratories or to intrinsic standards, where available. Where applicable, a specific traceability statement should be provided in the calibration certificate or report identifying the source of traceability, i.e., national or international laboratory or intrinsic standard. It is not necessary to state further identifiers such as bookkeeping numbers, NIST report numbers, etc. Stated numeric measurement results on calibration certificates or reports should include the associated uncertainties. For further background on the concept of traceability, and its evolution in defining the pathway to International System of Units (SI).

2.6.2.2 Example(s). All calibrations and/or verifications of the calibration laboratory equipment should be traceable to one ultimate source. However, not all equipment used in the laboratory requires traceability. For example:

1) Equipment used in an indicative mode or used for troubleshooting and repair. In these cases, absolute reference to an ultimate source is not necessary and may be an economic burden. Such equipment should not be in a recall system for calibration.
2) Equipment used as sources with other traceable instruments employed as measuring units for the output of these sources.
3) Those items remaining, in most instances, exhibit drifts and hence do require calibration and/or verification and should be traceable where available. The key here is "where available". It is quite possible that a certain measurement should be traceable but no ultimate standards or artifacts exist. In some cases, consensus standards are developed and used until (if ever) such times when official national or international standards have been approved for general use. It is important to note that "where available" should not be misused. The metrologist has to be sure that traceability is not possible in the national and international arena. The only way to know for sure is by networking with colleagues in related industries and personnel from the national and international laboratories. However, once a piece of equipment has been classified as needing traceability and there is a means of obtaining traceability, the calibration laboratory has several options shown below.
    a. Traceability through a sister organization. In this case, the traceable equipment is calibrated or verified at a related laboratory within the organization. This laboratory then has to be able to provide traceability to national, international, or intrinsic standards.
    b. Traceability through another commercial calibration laboratory. Once again, this commercial calibration laboratory has to be able to provide proof that the specific measurement required is traceable to national, international, or intrinsic standards.
    c. Traceability to national laboratories. In most cases this is the easiest, but also the most expensive, way to provide traceability. The National Standards Laboratory in the respective country should provide the ultimate traceable

measurement of a particular parameter. Just by making the measurement, stating its uncertainty, and providing an adequate calibration report with a specific date, traceability is guaranteed; there is no need to quote report numbers and any other non-value-added bookkeeping numbers. This report by itself is "traceability."

d. Traceability to international laboratories. Increasingly, a calibration laboratory will find that one particular National Standards Laboratory cannot provide traceability for all parameters, or that certain standards are only available in certain countries and hence measurement traceability has to be sought through those countries. This will become more apparent as the metrology community organizes itself into regions such as European, North America, and the Pacific Rim. Within each region, agreements might be reached that certain standards are maintained in certain countries and then use mutual agreements to recognize each other's standards.
e. Traceability to intrinsic standards which are physically stand-alone standards with a high degree of reproducibility. Performance wise, they have to be tied into intercomparison programs to avoid the possibility of system errors. With regard to types of intrinsic standards, several possibilities exist and the list of such standards is growing every year. Some examples are listed here:
   - Fundamental constants of nature.
   - Invariant properties of nature.

2.6.3 Alternatives. Where traceability to international, national, or intrinsic standards of measurement is not available, traceability requirements may be satisfied by:

a. Participation in a suitable program of interlaboratory comparisons or proficiency testing.
b. Internationally accepted standards in the field concerned.
c. Suitable reference materials.
d. Ratio or reciprocity-type measurements.
e. Mutual consent standards which are clearly specified and mutually agreed upon by all parties concerned.

2.6.3.1 Interpretive Guidance. In addition to traceability to national or international standards laboratories, the above items 0 through 0 can be used to fulfill traceability arguments.

2.6.3.2 Example(s). 1) Interlaboratory comparisons or proficiency testing. Industrial need for primary, traceable standards has put, in many cases, an overwhelming burden on the National Standards Laboratories (NSLs). To relieve the workload of these NSLs, interlaboratory comparisons have been established. These programs are also known as Measurement Assurance Programs (MAPs) or Round Robins (RRs). In cases for which official traceability to national standards is required, the participation of an NSL or an accredited laboratory (AL) is required to serve as the pivot laboratory, the overseer of the intercomparison. (Other MAPs or RRs without the participation of NSLs or ALs are very useful but do not carry the same weight in terms of traceability.) Many examples can be quoted for MAP or RR candidates: DC voltage, DC resistance, Capacitance, Fiber Optic, Power, UV

Sources, etc. In addition, intercomparison programs between NSLs are very common and are used to provide international definitions of particular parameters. Once agreed upon by the participating NSLs, these parameters can then be facilitated within a particular country through direct standards measurements or additional intercomparison programs. Examples would include AC voltage standards, spectral irradiance, etc. Proficiency testing may be required for accreditation. Any MAP or RR should help satisfy this requirement. In addition, measurements done one on one for a particular standard may constitute a proficiency test as long as either an NSL or an AL is one of the participating parties.

2) Internationally accepted standards. Several different types of standards fall into this category:
   a. Standards that are accepted internationally by all concerned. For example, mass with the unit of kg. (The only standard still maintained internationally as an artifact.)
   b. Standards that are agreed upon by the participating National Standards Laboratories (NSLs).
   c. Standards that are accepted internationally but not available in a particular country. In these cases, traceability by a calibration laboratory has to be sought on the international level without the involvement of its own national standardizing laboratory. For example, triple Point of Gases Cells for temperature.
3) Suitable reference materials. If no particular artifacts can be constructed or if artifacts cannot be maintained consistently, the traceability can be through reference materials. For example, thermal conductivity of graphite and metals, specular spectral reflectance (plate form), electrical resistivity and conductivity of metals, etc. Other Standard Reference Materials (SRMs) are used for the construction of artifacts or standards. Examples would be pure metals with four or five nines (99.999% pure). These SRMs, as utilized in standards, require additional approval in their implementation. Further examples include solution calorimetry, optical microscopy line width measurement (wafer form), photographic step tablets, etc.
4) Ratio or reciprocity-type measurements. Every calibration laboratory eventually gets involved in ratiometric measurements. The ratio as such cannot be made traceable. However, other parameters needed in the operation of these ratio devices should be traceable. In terms of reciprocity measurements, usually three devices of the same type are compared by ratio techniques. All possible ratio combinations are required and detailed calculations should be made to assure consistency of the measurements. For example, in the case of three devices, ratios 1:2, 1:3, 2:3 should be made. The results of these three intercomparisons may then be used to establish traceability.
5) Mutual consent standards. Every now and then, a situation occurs in a particular calibration laboratory for which no national, international, or intrinsic standard exists. In this case, all parties involved with the development and the use of that technology should coordinate their efforts and establish a Mutual Consent Standard. (It helps to have the NSL involved from the beginning.) Such mutual

consent standards require detailed intercomparison programs between the participants, a designated but arbitrary pivot laboratory, and constant vigilance. In most cases, the NSL in the particular country will eventually find a way to provide national or international traceability and standards. Once these have become available, the Mutual Consent Standards should be adjusted, if necessary.

2.6.4 Reference Standards Usage. Reference standards of measurements held by the laboratory shall be used for calibration or verification only and for no other purpose, unless it can be demonstrated that their performance as reference standards has not been invalidated.

2.6.4.1 Interpretive Guidance. Generally, a calibration laboratory employs reference and working standards with the former providing traceability to a particular source and the latter being used for calibration of equipment have to be employed with increased uncertainties. On the other hand, some laboratories use a single level of standards to accomplish both purposes. In this situation, great care should be taken to avoid degradation of the single level of standards. In addition, some means of checking them for damage, wear, and/or erratic behavior should be considered. Although the Standard does allow for a single level of standards within a laboratory, it specifically disallows for reference standards to be used for purposes other than calibration or verification unless it can be demonstrated that the performance of the reference standard has not been invalidated. Therefore, using the same item for frequent and routine measurements as well as a reference standard would be inappropriate unless special checks and precautions were made.

2.6.5 Reference Standards Calibration. Reference standards of measurement shall be calibrated by a competent body that can provide traceability. There shall be a program of calibration and verification for reference standards.

2.6.5.1 Any reference standards employed should be traceable to a competent source. It is to be understood that competent implies ability to prove adequacy of the calibration process and standards employed through detailed procedures and documentation, trend and control charts, and full uncertainty analysis.

The calibration laboratory should have a program in place that provides periodic calibration of the reference standards through a recall system. A laboratory in compliance with this Standard would be considered competent.

2.6.5.2 Example(s).

1) If the reference standard is calibrated by a national or international standards laboratory, then it is assumed that traceability is fulfilled and that adequate uncertainty is provided. It is up to the user of these standards to maintain the integrity of such standards through adequate handling, trend and control charts, or other intermediate checks as necessary.
2) If the reference standard is calibrated with an intrinsic standard by the same laboratory then full adequacy of calibration has to be maintained in terms of calibration processes, procedures, documentation, trend and control charts, and uncertainty analysis.

3) If the reference standard is calibrated by a laboratory not identified as a national or international standards laboratory, then that laboratory has to be prepared to show adequacy of the calibration process through detailed documentation of the procedures, trend and control charts, and uncertainty analysis. This laboratory also has to be able to prove full traceability for that standard.

2.6.6 Additional Validation. Where relevant, reference standards, measuring and test equipment shall be subject to in-service checks between calibrations and verifications.

2.6.6.1 Interpretive Guidance. In some applications, certain standards and equipment might require additional checks and verifications in addition to the normal calibrations performed based on the official recall system. Such checks help in providing trend and control charts, improve the maintenance of drift rates, and increase confidence in measurement capability.

Irrespective of the recall system, adequate trend and control charts should be maintained of the traceable reference standards. In some cases, the recall interval is short enough. In other cases, the laboratory should implement additional measures to ensure the integrity of the standards. This applies especially to those standards that exhibit large (compared to the quoted accuracies) drift rates. In most cases, though, a well monitored recall system should suffice to guarantee the integrity of the standards and other test and measuring equipment maintained by the laboratory. Items not needed for long periods or only required if and when a special test arises, could be put into a temporary storage category with the understanding that they will be calibrated prior to the next use.

2.6.6.2 Example(s). Sometimes a standards laboratory may elect to use a check standard to monitor a reference standard between regular calibrations.

2.6.7 Reference Material. Reference materials shall, where possible, be traceable to national or international standards of measurements, or to national or international standard reference materials.

2.6.7.1 Interpretive Guidance. Reference materials used in the calibration laboratory should be traceable to some ultimate source. Such sources could be national or international standards laboratories, or vendors whose products are recognized by such laboratories.

2.6.7.2 Example(s). Whenever reference materials are utilized in a calibration laboratory, their origin should be clearly stated. In most cases, reference materials such as Standard Reference Materials (SRMs) are available from National Standards Laboratories directly and hence national traceability is assured. In other cases, materials might be available from vendors with clear explanations of how the materials were proven to be of the stated quality. In these cases, some form of traceability has to be available with the materials.

2.7 Calibration Methods and Procedures

2.7.1 Documentation. The laboratory shall have documented instructions on the use and operation of all relevant equipment, on the handling and preparation of items, and for calibrations/verifications, where the absence of such instructions could jeopardize the

calibrations/verifications. All instructions, standards, manuals, and reference data relevant to the work of the laboratory shall be maintained up-to-date and be readily available to the staff.

2.7.1.1 Interpretive Guidance. Documentation of the calibration/verification process is usually necessary to maintain repeatability of measurement(s). This includes documentation of the process and the necessary instructions to properly operate the standards, the device being tested, and any ancillary equipment that directly affects the calibration/verification. Some items being calibrated require special handling and preparation.

The documents should be current to support the calibration/verification process. Technicians and engineers performing calibrations should be able to access the needed documentation within the laboratory, offices in close proximity to the laboratory or other suitable location near the workplace. The person responsible for performing the calibration/verification should not only be able to obtain the needed documents, but needs to know when and what changes have been made that may affect the process.

Documented instructions do not necessarily mean hard copy documents. Documentation can be in the form of software, CD ROM, microfilm, or other suitable media.

2.7.1.2 Example(s). The detail of the instructions necessary to accomplish a measurement varies according to the skill and experience of the metrology engineer or technician, the complexity of the calibration being performed and how often that the calibration is performed. Entry level personnel use detailed instructions and well written procedures to master each new measurement they perform. A very senior engineer performing the same procedure on a daily or weekly basis may not need to refer to the documentation as often. However, should a manual or procedure change be made and not properly annotated, a problem could arise that could make the calibration/verification invalid. Documentation can include:

1) Calibration procedures or procedure checklists.
2) Equipment installation, operator and service manuals.
3) Reference books, such as CRC Engineering Tables, ISO International Vocabulary, technical textbooks, and equipment manufacturer's application notes.

2.7.2 Use of Calibration Methods and Procedures. The laboratory shall use appropriate methods and procedures for all calibrations/verifications and related activities within its responsibility (including, but not limited to, sampling, handling, transport and storage, preparation of items, estimation of uncertainty of measurement and analysis of calibration data).

a. Calibration procedures shall contain the required range and tolerance or uncertainty of each item or unit parameter being calibrated or verified. In addition, the procedures shall contain the generic description of the measurement standards and equipment needed with the required parameter, range, tolerances or uncertainties, and specifications for performing the measurement of the calibration or verification, and/or representative types (manufacturer, model, option) that are capable of meeting the generic description for the measurement standards. The procedures shall be consistent with the accuracy required, and with any standard specifications relevant to the calibrations/verifications concerned.

b. The laboratory shall ensure that the calibration uncertainties are sufficiently small so that the adequacy of the measurement is not affected. Well defined and documented measurement assurance techniques or uncertainty analyses may be used to verify the adequacy of a measurement process. If such techniques or analyses are not used, then the collective uncertainty of the measurement standards shall not exceed 25% of the acceptable tolerance (e.g., manufacturer's specification) for each characteristic of the measuring and test equipment being calibrated or verified.

2.7.2.1 Interpretive Guidance. The method of calibration employed should be appropriate for the parameter being calibrated/verified. A detailed calibration procedure should be available and followed to the degree necessary for the calibration/verification being performed. The use of well documented calibration procedures is desired in order to maintain consistency of the measurement process when performed at different times and by different operators.
The standards selected and their associated uncertainties or tolerances should be adequate for the calibration/verification being performed.

2.7.2.2 Example(s).

1) An appropriate method or measurement technique is one that meets the needs of the calibration/verification being performed.
2) Some possible sources of calibration procedures are manufacturer's procedures, and military calibration procedures. Example sources include Army Technical Bulletins, Air Force Technical Orders, Navy NAVAIR publications, in-house developed procedures, and the Government Industry Data Exchange Program (GIDEP). All procedures need to be evaluated to ensure that they meet the needs of the calibration/verification being performed. When using the standards prescribed by the procedure it is recommended that, the uncertainties and related Test Accuracy Ratio (TAR) be reviewed.
3) It is generally considered good practice to identify all the sources of uncertainty which could affect a measurement process and to quantify these effects. Many laboratories accomplish this by creating a list of uncertainties called an "uncertainty budget." The magnitude of each uncertainty is then determined and recorded in the budget. Some sources of uncertainty listed in the budget may be found to be insignificant. This fact is noted in the budget. Having identified and quantified all relevant sources of uncertainty, their degree of interdependence should be evaluated. There are standard formulae such as the Welch-Satterthwaite equation for expressing this relationship. The next step is to combine all the components to produce a "combined standard uncertainty". This combination is accomplished by using a precisely defined mathematical relationship which is selected according to the number and relationship of the components. Finally, depending upon the level of confidence at which the laboratory has chosen to operate, the "combined standard uncertainty" is multiplied by a "coverage factor", k, which results in the "Expanded Uncertainty". If the Expanded Uncertainty is reported, then the associated coverage factor, k, should be included. A detailed explanation of the complete

process of expressing measurement uncertainty can be found in the "ISO Guide to the Expression of Uncertainty in Measurement" (Reference 2.2i). As a default alternative to doing an uncertainty analysis, a laboratory may rely on a Test Accuracy Ratio (TAR) of 4:1. A TAR of 4:1 means that the tolerance of the parameter (specification) being tested is equal to or greater than four times the combination of the uncertainties of all the measurement standards employed in the test. If it is determined that the TAR is less than 4:1, then one of the following methods may be used: uncertainty analysis as described above, guard-banding, widening the specification, or another appropriate method. (Note: Some refer to TARs as Test Uncertainty Ratios or TURs.)

4) The NCSL Recommended Practice RP-3. Calibration Procedures Content and Format, provides good guidance on how a calibration procedure may be written.

2.7.3 Standard Calibration Methods and Procedures. Where methods are not specified, the laboratory shall, wherever practical, select methods that have been published in international or national standards, those published by reputable technical organizations or in relevant scientific texts or journals.

2.7.3.1 Interpretive Guidance. The laboratory performing the calibration/verification should be using an acceptable calibration method or procedure. If the equipment manufacturer or the customer does not prescribe a method or procedure, then one must be developed or obtained from another source.

2.7.3.2 Example(s). References to measurement techniques can be found in textbooks, scientific papers, professional journals, and from the results of measurement research. Examples include:

1) Textbooks.
2) International Standards.
3) National standards: MIL-STD-461D and 462D, American Society for Testing and Materials (ASTM), American National Standards Institute (ANSI), American Society of Mechanical Engineers (ASME), Instrument Society of America (ISA).
4) IEEE proceedings.
5) Workshop and symposium proceedings.
6) Metrologia.
7) NIST/NBS technical notes.
8) NIST/NBS special publications.

2.7.4 Alternatives. Where it is necessary to employ methods that have not been well established, these shall be subject to agreement with the customer, be fully documented and validated, and be available to the customer or other recipients of the relevant reports.

2.7.4.1 Example(s). Some techniques for validating measurement methods are:

1) Technical reviews by others in same industry or discipline; these often have to rely upon "consensus methods."

2) Reviews by engineers with specialty experience in the discipline.
3) Evaluation and/or review by scientific investigation.
4) Obtaining acceptance by the measurement community, or "benchmarking."
5) Customer verification that the calibration data or acceptance criteria provided satisfies the needs of the application.
6) Repeating the measurement by a second method and comparing the results.

2.7.5 Sampling Methods. Where sampling is carried out as part of the calibration method, the laboratory shall use documented procedures and appropriate statistical techniques to select the samples.

2.7.5.1 Interpretative Guidance. Where the calibration method requires the use of a population or a sample of a population of measurements, appropriate statistical techniques should be used.

Statistical and quality textbooks, software programs and government standards (MIL-STD 105D) provide tables of random numbers and procedures for selecting random samples. These same references also help determine how many samples are necessary for a valid statistical test. The selected method should be documented and become part of the calibration procedure and the complete documentation package.

2.7.6 Calculations and Data Transfers. Calculations and data transfers shall be subject to appropriate checks.

2.7.6.1 Example(s). Some appropriate checks may include:

1) Review of calculations.
2) Comparison to previous results.
3) Standard data sets.
4) Review of abnormal and/or unexpected results.
5) Comparison of original data sheet against the final report.
6) Investigation of out-of-tolerance results.

2.7.7 Data Automation. Where computers or automated equipment are used for the capture, processing, manipulation, recording, reporting, storage or retrieval of calibration data, the laboratory shall ensure that:

a. The requirements of this Standard are followed.
b. Computer software is documented and adequate for use.
c. Procedures are established and implemented for protecting the integrity of data. Such procedures shall include, but are not limited to, integrity of data entry or capture, data storage, data transmission and data processing.
d. Computer and automated equipment is maintained to ensure proper functioning and provided with the environmental and operating conditions necessary to maintain the integrity of calibration data.

e. It establishes and implements appropriate procedures for the maintenance of security of data including the prevention of unauthorized access to, and the unauthorized amendment of, computer records.

2.7.7.1 Interpretive Guidance. This section relates strictly to calibration data. When automated procedures are used, the laboratory should ensure that the measurement is made correctly and the calibration is not invalidated. The user of the calibration results expects that instruments calibrated, data taken, and calculations accomplished are correct, private (secure) and have not been tampered with or corrupted.

1) The use of automated calibration processes does not relieve the laboratory of its responsibility to meet all of the requirements of the Standard.
2) This applies to both purchased and internally developed software. Since the Standard does not identify specific requirements, each laboratory should define its own needs for software documentation and adequacy.
3) Integrity means that the data has not been corrupted nor tampered with.
4) Computers and peripheral equipment used for calibration processes have recommended environmental operating needs and routine maintenance procedures that ensure their continued operation.
5) This section of the Standard addresses the issue of security against corruption of data as well as maintaining its confidentiality. Each laboratory should determine the level of security needed to adequately protect its data. Laboratories with many different operators and a more complex system may require more elaborate security measures than a laboratory with a single operator and limited access.

2.7.7.2 Example(s).

1) None offered
2) Documentation elements to consider:
   a. Inventory of utilized software
   b. Records of software performance tests
   c. Hardware operating system
   d. Operating instructions
   e. Software verification procedures using known data sets
   f. Program listing
   g. Program flowcharts
   h. Configuration control system
   i. System management
   j. Backup procedures
   k. Data archival
   l. Password protection
   m. Read/Write protection
   n. Hierarchical user access scheme

Documentation of software is a requirement of the Standard. This documentation may be within the program or in accompanying documents. Written instructions on how to load, execute and process a particular program are recommended. Screen prompts to assist the

operator with the steps of the procedures, connections, and any precautions are desirable. Some calibrations can be accomplished with a single connection and the equipment can then be left unattended until the program is complete and the report printed. Therefore, the level of operator intervention is an indicator of how extensive the operator instructions in the documentation should be.

Testing of software provides objective evidence of its adequacy. All software should be tested prior to use and periodically thereafter. One method of testing or verifying the software would be to compare measurement values taken by the automated process with those taken manually. The periodic use of a check standard could also provide a reliability check of the software.

3) Care in the processing of calibration data can be demonstrated by documenting periodic tests of the software and computer system. Tests can be developed for algorithms to ensure that calculations are being accomplished correctly. Frequent backups of the system discs can ensure that data is recoverable. Clearly identifying the latest revision of software being used can ensure that the latest changes or corrections have been accomplished. Maintaining calibration programs on a local area network (LAN) or shared resource manager (SRM) with a designated system administrator can be effective in reducing errors in handling software and saving files.

   Calibration reports can sometimes have faults which could indicate possible problems with the calibration itself or with data reduction. Reading the calibration report and reviewing the data can help eliminate problems which may have occurred during the calibration.
4) None offered.
5) Security to protect the computer system, the software and the calibration data can be demonstrated. Access to program code should be limited to reduce the possibility of changes to test points, limits, and data. System administrators and programmers are usually authorized to change program code. Prohibition of unauthorized operators can be accomplished with a system of log-on protocols and passwords that are changed frequently. A positive system backup process, repeated frequently, is a good plan to ensure data is not lost and is recoverable.

   Routine screening for computer viruses is a good plan to protect programs and archived data.

2.7.8 Consumable Materials. Documented procedures shall exist for the purchase, reception and storage of consumable materials used for the technical operations of the laboratory that can affect the results of calibrations.

2.7.8.1 Interpretive Guidance. This requirement addresses procedures and not the quality of consumables.

2.7.8.2 Example(s). One method of documenting the purchase of consumables might be to use an approved vendor list along with a procedure for its use. Receiving inspection of these

products is appropriate to ensure that the correct product has been delivered as specified by the purchase order. Handling and storage of this material may require special procedures, especially for flammable, toxic or dangerous materials. Where appropriate, Material Safety Data Sheets (MSDS) should be obtained and reviewed. Examples of consumables are:

1) Fluid for oil or temperature baths.
2) Special preservatives for machined surfaces.
3) Reagent grade chemicals.
4) Certain cleaning compounds or fluids.
5) Compressed gases.
6) Certain grades of cloth or paper wipes.
7) Batteries.

Material used in the routine operation of the laboratory such as office, hygiene, and housekeeping products normally do not require documented controls as outlined in this paragraph.

2.8 Handling of Calibration Items

2.8.1 Documentation. The laboratory shall have a documented system for uniquely identifying the items to be calibrated, to ensure that there can be no confusion regarding the identity of such items at any time.

2.8.1.1 Interpretive Guidance. The laboratory should have a documented process for tracking all equipment and standards received for calibration for the purpose of identifying ownership, special calibration requirements, special handling, or other details unique to each item. This should apply whether or not the equipment comes from sources within the company or from sources outside the control of the laboratory performing the calibration.

2.8.1.2 Example(s). One common method of uniquely identifying items received for calibration is to generate a "work order" or "service requisition" document that can be attached to the item and serve as a job traveler. This document generally identifies the item with such information as asset number, manufacturer, model, serial number, etc. It should also provide information that identifies ownership of the item. Other information included on this form might be calibration procedure number, special calibration requirements (limited calibration: calibrating one range of a multiple range device), and billing information (purchase order number etc.).

2.8.2 Records. Upon receipt of the calibration item, any abnormalities or departures from standard condition as prescribed in the relevant calibration method shall be recorded. Where there is any doubt as to the item's suitability for calibration, where the item does not conform to the description provided, or where the calibration required is not fully specified, the laboratory shall consult the customer for further instruction before proceeding. The laboratory shall establish whether the item has received all necessary preparation, or whether the customer requires preparation to be undertaken or arranged by the laboratory.

2.8.2.1 Interpretive Guidance. The laboratory should have a documented system that describes the process of treating departures and abnormalities from the norm at any point in the calibration process from receipt to return of items to be calibrated. There should also be a procedure for documenting and bringing such abnormalities to the attention of the customer or user so that problems are properly identified and if possible resolved.

2.8.2.2 Example(s). Some examples of abnormal events are:

1) Physical damage during shipping or handling while in transit from the customer to the laboratory or while in the laboratory.
2) Items submitted for calibration that are not capable of meeting requested calibration requirements. A customer or user may ask more of the calibration than the item is capable of meeting. For general purpose equipment, some laboratories use a "Limited Calibration" label or tag to identify conditions that are outside normal requirements. Limitations on the calibration can also be documented in a Report of Calibration.

3) Equipment failure during the calibration. There should be a definite procedure followed when such events occur. All such events should be documented for customer feedback as well as the historical record.

2.8.3 Handling. The laboratory shall have documented procedures and appropriate facilities to avoid deterioration or damage to the calibration item, during storage, handling, preparation, and calibration; any relevant instructions provided with the item shall be followed. Where items have to be stored or conditioned under specific environmental conditions, these conditions shall be maintained, monitored and recorded where necessary. Where a calibration item or portion of an item is to be held secure (for example, for reasons of record, safety or value, or to enable check calibrations to be performed later), the laboratory shall have storage and security arrangements that protect the condition and integrity of the secured items or portions concerned.

2.8.3.1 Interpretive Guidance. There should be a documented system in place that describes the procedures for protecting calibration items from loss, damage, or deterioration, or other condition that may affect the integrity of the equipment or the calibration results. Customer or user supplied handling and preparation instructions should be carefully followed. This applies to both pre and post calibration. If there are requirements to store or handle items in a specific manner, then these requirements should be clearly recorded and transmitted to all those that have a need to know.

2.8.3.2 Example(s). Long term storage of equipment may require special consideration such as items with batteries, which should be removed if there is a possibility of corrosion. Items put into long term storage which contain passive but delicate electronic components should be identified as requiring calibration before usage.

Restraint of portions of an item for safety reasons should not in any way damage the item or affect the calibration. An item that measures high pressure may have hoses that should be restrained so that if one were to burst or come loose there would be no chance of personal injury. High pressure devices should also be behind protective shields. All devices that have the ability to cause injury should have handling precautions carefully considered. Read instruction manuals and consult with safety engineers regarding a specific application.

2.8.4 Safety. The laboratory shall have documented procedures for the receipt, retention or safe disposal of calibration items, including all provisions necessary to protect the integrity of the laboratory.

2.8.4.1 Interpretive Guidance. Items received for calibration should do nothing to adversely influence any measurements in the laboratory if proper procedures are followed. Hazardous materials consumed in the calibration process should be disposed of in accordance with local safety or environmental regulations.

2.8.4.2 Example(s). Hazardous materials should have clear procedures written and followed, not only to establish proper handling technique, but also to specify what should be done in the event of accidents. For example, items containing mercury (barometers) should have special handling instructions so that there is no possibility of a mercury spill. Proper safeguards should

be in place to prevent accidents. In addition, proper training of personnel with access to the laboratory should be provided. This includes people not normally in the laboratory such as clerks and after-hours maintenance personnel.

2.8.5 Seals. Tamper-resistant seals shall be affixed to operator accessible controls or adjustments on measurement standards or measuring and test equipment which, if moved, will invalidate the calibration. The laboratory's calibration system shall provide instructions for the use of such seals and for the disposition of equipment with damaged or broken seals.

2.8.5.1 Interpretive Guidance. Operator accessible adjustments should be sealed so that if the adjustment is moved, there is an indication that the calibration may not be valid. The use of seals on measurement equipment and standards provides a visual means to the user and customer that the calibration adjustments have not been tampered with since the last authorized entry or calibration.

2.8.5.2 Example(s). Some schemes for accomplishing this task are:

1) Calibration adjustments may be sealed with torque paint.
2) Tamper-resistant seals may be used over equipment covers or doors so that individual adjustments need not be sealed.
3) Lead wire seals may be used to seal doors on large consoles for the same reason listed above.
4) Some facilities may use dip seal on mechanical gages that are subject to wear, to indicate usage. (If the gage has not been used then re-calibration may not be required).

Whatever technique is used, there should be a clear procedure to be followed when seals are found broken. There should also be a process in place that evaluates the potential impact on products tested with equipment found to have disturbed adjustments.

2.9 Records

2.9.1 Laboratory Records. The laboratory shall maintain a record system to suit its particular circumstances and comply with any applicable regulations. The records for each calibration shall contain sufficient information to permit the repetition of the calibration. The records shall include the identity of personnel involved in preparation and calibration.

2.9.1.1 Interpretive Guidance. The Standard allows for a flexible approach to the maintenance of laboratory records as long as certain requirements are met. Specifically, the Standard requires that the recorded information is adequately detailed to allow a calibration to be repeated, and that the individual(s) who did the work are identified. The individuals may have been involved in preparation, and/or calibration. Preparation may include activities which would affect the outcome of the calibration such as cleaning of the instrument to be calibrated or setting up the test equipment. The record system should provide confidence in the validity of the data and support consistent results from calibration to calibration. The records should be kept intact and uncorrupted. Data integrity and reliability are of the utmost importance.

Records may also have to comply with certain regulations which are specific to the customer, contract, industry, type of instrument or its application, geographic location, or agency. Agencies may be local, state, federal, or international.

2.9.1.2 Example(s). The laboratory's record system may be physically (hard copy) or electronically generated and maintained depending on the needs of the particular laboratory, the customer, and regulatory agencies. Considerations include data integrity, speed and ease of generation and maintenance, data retrieval requirements, volume of records, and record retention requirements.

The laboratory record must include the identity of personnel involved in the preparation and calibration. This may be in the form of the individual's name, or a uniquely assigned identifier. The latter requires a cross-reference between the identifier and the identity of the individual. The integrity of the identification is important. This may require a signature of the individual, an exclusive rubber stamp, a computer password, or other unique way of assuring the correct identity of the individual responsible.

2.9.2 Bookkeeping. All records (including those pertaining to calibration equipment), certificates, and reports shall be safely stored and held secure and in confidence to the customer for the period specified in the quality manual.

2.9.2.1 Interpretive Guidance. The quality manual must clearly state the records retention time period. The information should be treated as proprietary to the customer. Whether records are maintained on paper or electronically, they should be safely stored and protected from accidental or inappropriate alterations or destruction.

Records may be charged for the purposes of correction or some other appropriate reason, but a traceable history of these changes should be preserved. A common practice to accomplish this is to draw a single line through the material to be changed and to date and initial the alterations.

2.9.2.2 Example(s). A specific policy for records retention is recommended. Retention may be based on a specific calendar period, on a number of calibration cycles, or some other system that is well defined. The record retention period should be understood and acceptable to calibration customers.

Hard copy documents should be kept in a safe place that does not adversely affect the document.

Computer data, the disk, tape backup or other electronic media storage shall keep the data safe and retrievable. Electronic media history should be read-only after the calibration event. If it is reasonably possible for computerized historical data to be altered after the event of calibration, a hard copy should be kept as the "record copy."

2.10 Certificates and Reports

2.10.1 Documentation of the Results. When a certificate or report is issued, the results of the calibration, or series of calibrations carried out by the laboratory shall be accurate, clear, unambiguous and objective, in accordance with any instructions in the calibration methods. The results should normally be reported in a calibration report or certificate and shall include all the information necessary for the interpretation of the calibration results and all information required by the method used.

2.10.1.1 Interpretive Guidance. This requirement addresses the documentation of results of calibration and not if/when a certificate or report is issued. In some cases no documentation is provided other than a calibration label affixed to or accompanying the device. The requirement addresses the reliability, clarity, completeness and efficiency of documented results when documentation is provided to the customer.

2.10.1.2 Example(s). The Standard does not distinguish between a Calibration Report and a Calibration Certificate. (Calibration certificate or report: "Document that presents calibration results and other information relevant to a calibration.") When no distinction is made, otherwise identical documents could be entitled either "Report of Calibration" or "Certificate of Calibration" and be in compliance with the Standard. However, this blurring of the distinction between calibration reports and certificates is not universally followed either in the US or elsewhere. One practice, used by many calibration organizations in the US, is described in the NCSL's RP-11, which distinguishes between reports and certificates. For example, a document which includes measurement data is sometimes called a "Report of Calibration" whereas a document which states conformance to a tolerance specification is sometimes called a "Certificate of Calibration", even if measurement data is also included.

2.10.2 Format and Contents. Each certificate or report shall include at least the following information:

1) A title, e.g. "Calibration Report" or "Calibration Certificate."
2) Name and address of laboratory, and location where the calibration was carried out if different from the address of the laboratory.
3) Unique identification of the certificate or report (such as serial number) and of each page, and the total number of pages.
4) Name and address of customer, where appropriate.
5) Description and unambiguous identification of the item calibrated.
6) Characterization and condition of the calibration item.
7) Date(s) of performance of calibration, where appropriate.
8) Identification of the calibration procedure used, or unambiguous description of any non-standard method used.
9) Reference to sampling procedure, where relevant.
10) Any deviation from, additions to, or exclusions from the calibration method, and any other information relevant to a specific calibration, such as environmental conditions.
11) Measurements, examinations and derived results, supported by tables, graphs, sketches, and photographs, as appropriate, and any failures identified.

12) A statement of the estimated uncertainty of the calibration result (where relevant).
13) A signature and title or an equivalent identification of the person(s) accepting responsibility for the content of the certificate or report (however produced), and date of issue.
14) Where relevant, a statement to the effect that the results relate only to the items calibrated.
15) A statement that the certificate or report shall not be reproduced except in full, without the written approval of the laboratory.
16) Special limitations of use.
17) Traceability statement.

2.10.2.1 Interpretive Guidance.

1) The laboratory may choose other titles for its reports or certificates. The essential point is that a title be included.
2) None offered.
3) None offered.
4) None offered.
5) None offered.
6) If the device as received appears to have been dropped or otherwise subjected to improper handling or storage this fact should be included on the Certificate or Report of Calibration. If the as-received conditions were such that contact with the customer was made prior to the start or completion of the calibration any special comments or instructions from the customer should be noted or referenced. Also include whether the device was in-tolerance or out -of-tolerance as received.
7) Generally, the calibration date reported is the last day during which measurements were performed. Where calibration is completed substantially earlier than the certificate, or is performed over several days, this information might be provided.
8) Sufficient information should be provided to allow for the replication of the calibration.
9) There may be times when the results of the calibration or verification on samples of a batch or lot of devices of the same description may be extended to apply to other devices in the same batch or lot from which the samples were chosen. When this is the case it should be so noted along with a description or reference to a documented procedure describing valid statistical or other techniques for selection of samples.
10) The first part of this requirement is similar to h) above and could be accomplished by referencing a uniquely identified procedure with exceptions. The second part requires the reporting of influence quantities such as temperature, humidity, gravity, etc., that may affect the reported values beyond the reported uncertainties.
11) Measurements, examinations, and/or derived results should be supplied as appropriate to customer and laboratory requirements. Any failures identified will always be supplied. Calibration results may be reported in one of many forms. See the examples which list some possibilities. Tables, graphs,

sketches, and photographs may be supplied when appropriate to support measurements, examinations, and derived results.

12) Where actual values are reported (as requested by the customer which may also be the laboratory itself) the uncertainty associated with the value(s) should be reported.
13) The person responsible for the report or the certificate, not necessarily the person who performed the calibration, should be readily identifiable. The date the report is issued should also be included.
14) Where necessary to avoid the implication that the results may apply to other identical or related devices, a statement that such is not the case should be offered.
15) None offered.
16) When a special or limited calibration is performed, the Calibration Report or Calibration Certificate should contain a notice that alerts the user that a special limitation-of-use condition exists and identifies the nature of the limitation(s).
17) Reports and Certificates should state the traceability to national, international or intrinsic (reference) standards. Where such traceability does not exist, it should state which alternative applies to the calibration or verification being documented.

2.10.2.2 Example(s).

1) Other possible titles could be Data Sheets, Report of Calibration, and Certificate of Conformance.
2) None offered.
3) Some examples of unique identifiers for each certificate and/or each page might be a report or certificate number, job number, sales order number, serial number of the equipment, and date of calibration. Examples of page numbering might be "page 1 of x," or "1/x.", or the total number of pages on cover page with each page numbered.
4) Situations where a name and address may not be required include classified programs, and warehouse products for sale.
5) Some examples could be item nomenclature; manufacturer, model, and serial number; nomenclature and asset number; nomenclature and property number; nomenclature and control number.
6) Some examples of conditions that might be noted are damaged items, out-of-tolerance, intolerance, inoperative, and accessories missing.
7) An example where a range of dates may be reported is DC voltage standards usually require sets of measurements taken over specific periods of time in order to determine the drift rate.
8) Some examples of identifying standard procedures would be to call out its procedure number, reference a section of a manufacturer's manual, reference an industry or government standard (e.g., ASTM, NCSL, ASME, etc.). Some examples for identifying non-standard methods are to reference a standard procedure indicating any departures from it; to explain in detail how the method was executed; then create an ad hoc method, uniquely identify it, and reference it.

9) None offered.
10) An example might be the temperature at which a measurement(s) was made in the calibration process. Also temperature limits, not stated in the procedure or specification, beyond which the calibration is not valid. The latter example also addresses a "special limitation of use").
11) Some examples of calibration results might be: for single parameter units, a pass/fail statement may be adequate; a statement of compliance with a specification, such as statement that instrument meets manufacturer's requirements; numerical measurement data only; measurement data, applicable correction factors, and appropriate calculated results; deviations from nominal.
12) Some examples where reporting an uncertainty statement would usually be relevant are where values are assigned to reference standards; where numerical results are reported and no tolerance specification is identified. An example where reporting an uncertainty statement would usually not be relevant is when stating conformance with a specification with or without data.
13) Some examples of equivalent identification may be an identifier which is appropriately controlled, or a unique personal identification number. Some examples of how the identifier could be produced are a rubber stamp, a bar code, and a computer-generated identifier.
14) For example, when only selected instruments within a multiple instrument test stand are being calibrated, the report should indicate this situation.
15) None offered.
16) Examples of such special or limited calibrations are:
    a. Not all functions on a multi-function device are calibrated.
    b. All ranges on a multi-range device not calibrated.
    c. May not be used above 27 ^{o}C.
    d. Performance is optimized on a specific range or function.
17) None offered.

2.10.3 Subcontract. Where the certificate or report contains results of calibrations performed by subcontractors, these results shall be clearly identified.

2.10.3.1 Interpretive Guidance. If all or part of the calibration is performed by a sub-contractor, this fact must also appear on the report or certificate as well as appropriate other related information, e.g. identification, location, etc. of the sub-contractor.

2.10.4 Standardization. Particular care and attention shall be paid to the arrangement of the certificate or report, especially with regard to presentation of the calibration data and ease of assimilation by the reader. The format shall be designed carefully and specifically for each type of calibration performed; however, the headings shall be standardized as much as possible.

2.10.4.1 Interpretive Guidance. The concept behind this section is to promote the ease of use and review through a combination of reasonable flexibility and standardization, and to ensure that necessary information unique to a particular calibration is not omitted. It is considered good practice to standardize elements common to all reports generated within a laboratory.

2.10.5 Amendments. Material amendments to a calibration report or calibration certificate after issue shall be made only in the form of a further document, or data transfer including the statement "supplement to calibration report [or calibration certificate], serial number...[or otherwise identified]", or equivalent form of wording. Such amendments shall meet all the relevant requirements of this Standard.

2.10.5.1 Example(s). Material amendments may include revision of the actual data; correction of erroneous calculations, data transcription errors, erroneous calibration dates; insertion of omitted data.

2.10.6 Notification. The laboratory shall notify customers promptly, in writing, of the following:

1) Any event such as the identification of defective calibration equipment that casts doubt on the validity of results given in any calibration report or certificate, or amendment to a report or certificate. Such notification shall quantify the magnitude of error created in the calibration results.
2) Any customer's measuring and test equipment found significantly out-of-tolerance during the calibration/verification process. Measurement data shall be reported so that appropriate action can be taken.

2.10.6.1 Interpretive Guidance. The users of M&TE and measurement standards should be notified when:

1) Any condition which casts doubt on the validity of results of any previous calibration report or certificate. The latter might include such occurrences as discovery of an out-of-tolerance (OOT) calibration standard, errors in calibration procedure, or computer entry error, that adversely affects calibration results.
2) Any instrument found to be significantly OOT. Agreement should be reached by the customer and the calibration laboratory as to what constitutes “significantly

out-of-tolerance". In most cases, the customer is in a better position to determine what is "significant" because he is aware of the equipment usage and application. However, the customer may wish to take advantage of the calibration laboratory's expertise and experience in this matter. Therefore, experience has shown that the best decisions are made by mutual agreement on this topic. If such agreement is not possible, the laboratory should have a documented policy on this issue. The purpose of the above notifications is to alert the customer of any condition which could have caused erroneous measurements. This enables the customer to take appropriate corrective action. For example, M&TE or measurement standards would be considered "significantly" OOT when their condition could adversely affect product quality, measurement integrity, or safety. The specific parameter and magnitude of the OOT condition which constitute adverse consequences is dependent upon the use and application of the M&TE or measurement standard.

2.10.6.2 Example(s). Instances which may cast doubt on previous calibrations should be addressed by the laboratory. Examples of such occurrences may include:

1) Later discovery of erroneous data transcription.
2) Calibration standards later found OOT.
3) Computer software errors.
4) Later discovery of calibration procedure errors.

One approach to defining "significant OOT" for a laboratory may require reporting of all OOT M&TE and measurement standards systems to the user and/or customer if appropriate. In this case, determination of significance of the OOT condition is then left to the user and/or the customer.

The laboratory may alternatively ask the user and/or customer to specify in advance of calibration which instruments, which parameters, and what degree of OOT would result in adverse effect on product quality, measurement integrity, or safety. The laboratory may then report only those "significant" OOT occurrences.

In addition to analysis of the use requirements of the OOT instrument, the ratio of the OOT condition to the accuracy requirement of the instrument should be considered. For example, if the test accuracy ratio between product parameter and M&TE is 10:1 (i.e. ±10 volts for the product parameter and ±1 volt for the M&TE), an M&TE OOT condition of 2.5 volts results in an effective test accuracy ratio of 4:1 (i.e. 10 volts for the product parameter and 2.5 volts for the M&TE). This should have little effect on the testing results of the product parameter. On the other hand, if a test accuracy ratio of 5:1 between the product parameter and the M&TE is initially established, and the M&TE OOT condition was 2.5 volts, the effective test accuracy ratio would degrade to 2:1. This may significantly impact the testing results of the product parameter. The laboratory may consider this to decide the "significance" of OOT conditions whether the decisions are made before or after the fact. An effective test accuracy ratio between M&TE and product parameter less than that required by the customer is not acceptable.

2.10.7 Transmission. The laboratory shall ensure that, where customers require transmission of calibration results by telephone, telex, facsimile or other electronic or electromagnetic means, staff will follow documented procedures that ensure that the requirements of this Standard are met and that confidentiality is preserved.

2.10.7.1 Interpretive Guidance. Electronic or electromagnetic transmission of results does not alleviate the laboratory's responsibility to issue a full report which meets the requirements of the applicable sections of the Standard. Electronic or electromagnetic transmission of calibration results can jeopardize the confidentiality. The laboratory should have documented procedures which address this issue.

2.10.7.2 Example(s). Some methods or techniques which minimize the risk to confidentiality are appropriately annotated fax cover sheets, back-up fax transmissions with a voice telephone contact to verify receipt, calling the intended recipient prior to transmissions.

2.11 Sub-Contracting of Calibration

2.11.1 Sub-Contractor's Qualification and Customer Notification. Where a laboratory sub-contracts any part of the calibration, this work shall be placed with a laboratory complying with the requirements of this Standard. The laboratory shall ensure and be able to demonstrate that its sub-contractor is competent to perform the activities in question and complies with the same criteria of competence as the laboratory with respect of the work being sub-contracted. The laboratory shall advise the customer of its intent to subcontract any portion of the calibration to another party.

2.11.1.1 Interpretive Guidance. All aspects of the calibration must conform to this Standard, including work that is sub-contracted. The laboratory is responsible to assure compliance by the sub-contracted laboratory and maintain objective evidence of that assurance. Notification of the intent to sub-contract the work should take place prior to the calibration. If using questionnaires as a means to audit a sub-contractor's quality, the examination of the results from recent sub-contractor site visits and actual artifact tests should be considered as a means of strengthening the use of this medium as evidence of compliance.

2.11.1.2 Example(s). There are several elements which could aid in collecting evidence that a sub-contractor is in compliance with the Standard. A few examples are:

1) On-site surveys or audits of the sub-contractor by the laboratory.
2) On site surveys or audits of the sub-contractor by another qualified auditing organization.
3) Use of questionnaire surveys of the sub-contractor.
4) Examination of the sub-contractor's quality manual.
5) Determination that the sub-contractor is accredited by an appropriate accrediting agency.
6) Examination of the results from the sub-contractor's participation in measurement assurance and laboratory intercomparison programs.

Accreditation of the sub-contractor against the requirements of the Standard is generally the preferred means by which the laboratory can be assured that the sub-contractor is in compliance. However, some of the other approaches listed above, or combinations of them, may prove to be adequate. For example, a laboratory may request that a sub-contractor complete a questionnaire survey, examine the subcontractor's quality manual, and require that the sub-contractor participate in a measurement assurance program. The laboratory might then determine the sub-contractor's compliance to the Standard through the combination of all three elements.

2.11.2 Documentation. The laboratory shall record and retain details of its investigation of the competence and compliance of its sub-contractors and maintain a register of all sub-contracting.

2.11.2.1 Example(s). A log or register of sub-contractors is commonly used for this requirement of the Standard. The documentation from the investigation must be traceable to the log or register and is compliance rated.

2.12 Outside of Support Services and Supplies

2.12.1 Quality Assurance. Where the laboratory procures outside services and supplies, other than those referred to in this Standard, in support of calibrations, the laboratory shall use only those outside support services and supplies that are of adequate quality to sustain confidence in the laboratory's calibrations.

2.12.1.1 Interpretive Guidance. The laboratory should procure only those outside support services and supplies conforming to all requirements to assure compliance to all calibration requirements. Where there is no specific quality requirement for the required outside goods and services, the laboratory should use acceptable common industry standards.

2.12.1.2 Example(s). If a piece of equipment is to be free moving and requires lubrication but no type of lubricant is specified, the choice should be appropriate to the performance and application requirements of the instrument without compromising either. Other examples might include:

1) Oils for temperature baths.
2) Mercury for barometers.
3) Pure chemicals and gases.
4) Equipment servicing, not to include calibration.

2.12.2 Quality Validation. Where no independent assurance of the quality of outside support services or supplies is available, the laboratory shall have procedures to ensure that purchased equipment, materials and services comply with specified requirements. The laboratory should ensure, wherever possible, that purchased equipment and consumable materials are not used until they have been inspected, calibrated or otherwise verified as complying with any standard specifications relevant to the calibrations concerned.

2.12.2.1 Interpretive Guidance. The laboratory quality manual should require that the identification of specific parameters for acceptance be defined either in the purchase order to the

supplier of goods or services and/or separate specifications, prints etc. A clear understanding of the characteristics of size, performance or other definable parameters and acceptance criteria when the products or services are received by the laboratory are essential for adequate conformance verification. The use of products that have not been inspected or service parameters that have not been verified may compromise the laboratory's ability to provide adequate data and history of the calibration or test.

2.12.3 Record Keeping. The laboratory shall maintain records of all suppliers from whom it obtains support services or supplies required for calibrations.

2.13 Complaints

2.13.1 Documentation. The laboratory shall have documented policy and procedures for the resolution of complaints received from customers or other parties about the laboratory's activities. A record shall be maintained of all complaints and of the actions taken by the laboratory.

2.13.1.1 Interpretive Guidance. The laboratory should have documented policies and procedures for addressing complaints against its activities. The laboratory's activities may be considered as any activity that relates to the quality of the service provided, including, but not limited to, calibrations, consultations, advertisement of its services, or advertisement of its accredited status (if applicable).

2.13.1.2 Example(s). The laboratory's system may be considered adequate when the policies and procedures require some type of record be maintained to document all complaints received and subsequent actions taken to resolve those complaints. The system used to address and resolve complaints can be as simple or as elaborate as needed. Simple log books may suffice in some operations and a complex computer data base may be needed in others. The complaint system may be tailored to the size of the calibration operation, type of customers serviced, contract requirements, or other criteria.

2.13.2 Actions. Where a complaint, or any other circumstance, raises a concern regarding the laboratory's compliance with the laboratory's policies or procedures, or with the requirements of this Standard or otherwise concerning the quality of the laboratory's calibrations, the laboratory shall ensure that complaints in those areas of activity and responsibility involved are promptly resolved.

2.13.2.1 Interpretive Guidance. The laboratory's documented policy and procedures should provide for the prompt resolution of all complaints regarding the quality of the laboratory's activities.

2.13.2.2 Example(s). The laboratory's documented policies and procedures regarding corrective actions may range from changing an internal procedure to recalling previously calibrated equipment. Internal policies and procedures dealing with compliance and quality issues should provide guidance for the resolution of all such issues as soon as possible and practical. Prompt resolution not only addresses the immediate complaint, it also attempts to identify and resolve the root cause of the complaint (i.e.: What went wrong? How do we prevent it from happening again?).

3 PART III:QUALITY ASSURANCE REQUIREMENTS FOR MEASURING AND TEST EQUIPMENT (M&TE)

Part III applies to the control of measuring and test equipment (M&TE) used to assure that supplies and services comply with prescribed customer requirements.

3.1 General Requirements

3.1.1 Documentation. The supplier shall establish and document a system to control the calibration/verification of M&TE.

3.1.2 Validation. M&TE used to determine compliance with technical specifications shall be calibrated or verified in accordance with PART II of this Standard.

3.1.3 Recall and Verification Program The supplier shall have a program to recall for calibration or verification, or remove from service, M&TE that has exceeded its calibration interval, has broken calibration seals, or is suspected to be malfunctioning because of mishandling, misuse, or unusual measurement results.

3.1.4 Periodic Verification. All operations performed by the supplier in compliance with this Standard shall be subject to verification at unscheduled intervals.

3.1.5 Periodic Auditing. The supplier shall carry out or arrange to be carried out, periodic quality auditing of the calibration and verification system in order to ensure its continuing effective implementation and compliance with the requirements of this Standard.

3.1.5.1 Assessments and Reviews. Based on the results of the audits, assessments and any other relevant factors, such as customer feedback, the supplier shall review and modify the system as necessary.

3.1.5.2 Documentation. Plans and procedures for the audits or assessments shall be documented. The conduct of the audit or assessment and any subsequent corrective action shall also be documented.

3.2 Detailed Requirements

3.2.1 Calibration System Description. 115The supplier shall provide and maintain a written description of the calibration/verification system covering M&TE. The description shall be sufficient to satisfy each requirement of
PART II of this Standard and any deviations shall be submitted with supporting justification to the customer for approval.

3.2.1.1 Interpretive Guidance. Documentation of all existing or proposed procedures and practices implementing the supplier's calibration/verification system is necessary to promote uniformity of understanding, continuity of operations when personnel changes occur and to provide a means of demonstrating the supplier's intent, criteria and approach in satisfying the

requirements of the Standard. The written description of the supplier's calibration/verification system should be relevant and contain complete current details of the system.

3.2.1.2 Example(s). The system description will describe the requirement, identify responsibility, and provide a method, procedure, or standard practice, including quantification where appropriate, for each specific requirement of the Standard. Any planned deviations by the supplier to the detailed requirements of the Standard are documented. The system description provides instructions for obtaining Customer review and approval of deviations from the Standard when required by the contract. A standardized format for the written calibration/verification system description is not required; documentation used in the inspection or quality program is generally appropriate. The supplier should ensure that changes to the calibration/verification system are reflected in the system description using some form of document control system.

3.2.2 Adequacy of Measurement Standards. Measurement standards used by the supplier for calibrating M&TE and other measurement standards shall comply with the requirements of 2 of the Standard.

3.2.2.1 Interpretive Guidance. See Section 2 of the Handbook.

3.2.2.2 Example(s). See Section 2 of the Handbook.

3.2.3 Environmental Conditions. M&TE shall be used in an environment controlled to the extent necessary to ensure valid results. Due consideration shall be given to temperature, humidity, lighting, vibration, dust control, cleanliness, electromagnetic interference and any other factors affecting the results of measurements. When pertinent, these factors shall be monitored and recorded and, when appropriate, correcting compensations shall be applied to measurement results.

3.2.3.1 Interpretive Guidance. Environmental conditions, such as temperature, relative humidity, vibration, electrical interference, dust, etc., which could affect the accuracy, stability, or precision of M&TE require control by the supplier. The degree of control necessary and the extent of compensation, when the required control is not achieved, are directly related to the impact of the environmental conditions on the specific use requirements of the M&TE. As a quality assurance measure, environmental conditions should be monitored and recorded.

3.2.3.2 Example(s). All M&TE is used in an area environmentally controlled to the degree necessary to assure accurate measurements. The supplier's written calibration/verification system description describes the environmental control requirements and how compensation, when such controls are not met, is identified and accomplished. In specific instances where defined environmental control requirements are not met, the supplier can demonstrate that such controls are not required or that he has adequately compensated for the lack of control through the use of corrections or other means.

3.2.4 Intervals of Calibration and Verification. M&TE requiring calibration shall be calibrated or verified at periodic intervals established and maintained to assure acceptable reliability, where reliability is defined as the probability that M&TE will remain in - tolerance throughout the interval. Intervals shall be established for all M&TE requiring calibration unless

the equipment is regularly monitored through the use of check standards in a documented measurement assurance process. Check standards must closely represent the item parameters normally tested in the process and the check standard must be verified periodically. Where intervals are used to ensure reliability, the interval setting system must be systematically applied and shall have stated reliability goals and a method of verifying that the goals are being attained. Intervals may be based on usage or time since last calibration or verification. All exemptions from periodic calibration or verification shall be documented. The recall system may provide for the temporary extension of the calibration due date for limited periods of time under specified conditions that do not unreasonably impair the satisfaction of the customers requirements.

3.2.4.1 Interpretive Guidance. The underlying basis for periodic calibration intervals is to establish some usage or time interval where there is a high probability that the instruments being calibrated will remain in-tolerance throughout the established interval. If this occurs, then the requirements of acceptable accuracy and reliability are met. Since the condition (in-tolerance or out-of-tolerance) of M&TE during the calibration interval is unknown, an inference regarding their condition must be made based upon their condition found at the end of the interval.

One technique used in the control of calibration intervals to achieve acceptable accuracy and reliability is a requirement for recall or verification at some established interval, continuing review and adjustment of the interval (lengthening or shortening) as required to maintain the acceptable reliability (also called the reliability target), and removal from use of M&TE that do not meet the reliability target after interval adjustment.

A check standard is some device or instrument that is similar in behavior to the items being submitted for calibration by the process that is to be controlled. By making regular measurements on one or more check standards that are known to be stable and reproducible, and plotting the data on a control chart, one can observe graphically any changes in the performance of the controlled process and M&TE. Statistical tests may then be used to determine the significance of any change in the behavior of the process and/or the M&TE

Criteria for removal or repair of instrument or compensation for environmental condition(s) should be established based on the results of the statistical test.

In the most rigorous approach to controlling the measurement process one makes a measurement on a check standard each time a measurement is performed. The measured values of the check standard are then plotted on a control chart and analyzed to determine if the process is in a state of statistical control. If the measurement on the check standard indicates an out-of-control condition, the measurement system is flawed and must be validated after the source of trouble is identified and corrected.

3.2.4.2 Example(s). The supplier's written calibration/verification system description defines what constitutes an acceptable probability for the instruments being in-tolerance (reliability target) during the calibration interval, how this probability is determined and the procedure for adjusting the interval when the reliability target is not met.

For some fixed value M&TE, the in-tolerance or reliability target criteria may be stated in terms of deviation from the last calibration value rather than deviation from a specific nominal value.

There are no restrictions as to what methodology is employed to initially establish a calibration interval to meet a specific reliability target or how the established interval is adjusted if the desired reliability is not being achieved.

Whatever methods are selected, the supplier can demonstrate how each M&TE and measurement standard, or homogeneous group thereof, meets the reliability target through use of the established calibration interval and how intervals have been adjusted when reliability targets were not met.

Specific reliability targets for M&TE may be established contractually or are determined by the supplier based on analysis of all pertinent factors.

The supplier may elect to use calibration intervals established by another laboratory. However, the supplier should be aware of the underlying reliability targets for these intervals and assure that they are compatible with all appropriate requirements.

All M&TE is included in the supplier's recall system.

Intervals are typically established in terms of calendar time months or days, usage, or a combination of both. Some instruments (usually measurement standards and/or check standards may be calibrated on a continuing basis as part of a measurement system under statistical process control (SPC) and will not have a finite calibration interval.

If the intervals are established on a usage basis, the supplier will define what constitutes usage. In any case, the supplier should maintain historical records for all calibrated M&TE to the extent that the adjustment of intervals can be verified.

The supplier's recall system will include instructions that provide for the following:

1) Recall of M&TE for calibration according to predetermined schedules when other control methods are not used.
2) Prompt release by the user of instruments recalled for calibration.
3) The issuing of calibration overdue notices.
4) The prevention of use, through impounding or other means, of overdue instruments.

The supplier's calibration/verification system may include provisions for a temporary extension of a calibration due date for a limited period of time under certain specific conditions, such as completion of a test in progress. If such provisions are included, the temporary extension must have an adequate and documented basis and be controlled.

Since the supplier has the ability to plan the use of M&TE, such extensions should be the exception rather than the rule.

The supplier's calibration/verification system will also provide for identification of M&TE that does not meet (or cannot meet) the reliability target after interval adjustment. Such instruments should have their use restricted or be removed from use.

3.2.5 Calibration Procedures. Procedures used to calibrate/verify the suppliers M&TE shall comply with the requirements of 2 of this Standard.

3.2.5.1 Interpretive Guidance. See Section 2 of this Handbook.

3.2.5.2 Example(s). See Section 2 of this Handbook.

3.2.6 Out-of-tolerance Conditions. If any M&TE is found to be significantly out of tolerance during the calibration/verification process, the suppliers system shall provide for notification to the user and appropriate quality element of the out-of-tolerance condition with the associated measurement data so that appropriate action can be taken.

3.2.6.1 Interpretive Guidance. The supplier's written calibration/verification system description will include a procedure which provides that the user of M&TE be notified of any instrument found to be significantly out-of-tolerance during calibration. The purpose of the notification is to alert the user to the possibility of erroneous measurements made by the significantly out-of-tolerance instruments.

The supplier's procedure providing for notification of significantly out-of-tolerance instruments will also define what constitutes "Significantly" out-of-tolerance.

3.2.6.2 Example(s). The supplier's written calibration/verification system description includes the requirement for recording and reporting significantly out-of- tolerance conditions identified during calibration of M&TE. The supplier's calibration/verification system includes a reporting format which provides for a description of the specific out-of-tolerance condition with supporting data, and the reporting channels to be followed. As a minimum, the reporting channels should include the instrument user and appropriate management responsible for the quality of the measurements.

The supplier's written calibration/verification system description describes what constitutes a "significant" out-of-tolerance condition.

M&TE should be considered "significantly" out-of-tolerance when their condition could adversely affect product quality, measurement integrity, or safety. The specific parameter and degree of out-of-tolerance condition which constitute adverse performance are largely dependent upon the use and application of the M&TE. Accordingly, determination of a "significantly" out-of-tolerance condition is generally based on an engineering analysis of the instrument's use requirements, the effect of the out-of-tolerance condition on the parameter being measured or calibrated, and ultimately the effect on the end-product or material being delivered.

The supplier's calibration/verification system description may establish a reporting system to notify the user and quality elements of all out-of-tolerance M&TE. The determination

of whether the out-of-tolerance condition significant or not is then left with the user and/or the quality component who have received the notice. However, if it can be determined beforehand which specific instruments, which specific parameters, and what degree of out-of-tolerance would result in an adverse effect on product quality, measurement integrity, or safety, then only "significantly" out-of-tolerance notices need be provided. In the first instance, the supplier reports all out-of-tolerance conditions and leaves it up to the recipient of the notice to make the decision as to "significant" or not. In the second instance, preliminary efforts are expended to determine what will constitute "significant" out-of-tolerance conditions, and only those so established are reported when they occur.

In addition to the aforementioned engineering analysis for determining whether the out-of-tolerance condition is "significant" or not, consideration should be given to the magnitude of the out-of-tolerance condition as contrasted with the accuracy requirement of the out-of-tolerance instrument. For example, if the test accuracy ratio between product parameter and M&TE were 10:1 (e.g., ±10 volts for the product parameter and ±1 volt for the M&TE), an M&TE out-of-tolerance condition of 2.5 volts would result in an effective test accuracy ratio of 4:1 (i.e. ±10 volts for the product parameter and ±2.5 volts for the M&TE), which should have little effect on the testing results of the product parameter. On the other hand, if a test accuracy ratio of 5:1 between product parameter and M&TE were initially established, and the M&TE out-of-tolerance condition was again 2.5 volts, then the effective test accuracy ratio would degrade to 2:1, potentially impacting the testing results of the product parameter.

The supplier may apply these considerations in his decisions as to what is "significantly" out-of-tolerance, whether these decisions are made before or after the fact, as described in the preceding paragraph. For example, for any given accuracy ratio, the risk of accepting a bad calibration or of rejecting a good calibration, can be evaluated statistically.

3.2.7 Adequacy of Calibration/Verification System. The supplier shall establish and maintain documented procedures to evaluate the adequacy of the calibration/verification system and to ensure compliance with the requirements of this Standard.

3.2.7.1 Interpretive Guidance. The Standard requires that the supplier provide a means to monitor and evaluate the calibration/verification system against the requirements of this Standard and to ensure that the system continues to fulfill contractual requirements.

This requirement places the responsibility on the supplier to perform the necessary quality control/quality assurance functions and inspections to verify that all aspects of the calibration/verification system are in compliance, to identify and evaluate possible and actual calibration/verification system problems, and to initiate appropriate safeguards and corrective actions.

3.2.7.2 Example(s). The supplier has established procedures including audits, inspections or other control functions for assuring that all aspects of the calibration/verification system are in compliance with the Standard specifically, the supplier will review and audit operations to assure compliance to the detailed requirements of the Standard concerning adequacy of measurement standards, environmental controls, calibration intervals, calibration procedures, out-of- tolerance reporting, calibration sources, record keeping, calibration labeling, subcontractor calibration, and

storage and handling. In addition to these specific requirements, the supplier's review may include related elements which could impact operations such as adequacy of M&TE, personnel, and training. The supplier has developed a system wherein all reports of problems or deficiencies uncovered in system audits or determined during normal operations are documented, thoroughly investigated and resolved.

The supplier can demonstrate how reviews and self-evaluations of the calibration/verification system are performed. Results of the reviews should be available. The supplier may wish to use the in-house quality component in lieu of the calibration laboratory in performance of these audits to ensure objectivity.

3.2.8 Calibration Sources. M&TE requiring calibration shall be calibrated or verified by laboratories meeting the requirements of 2 of this Standard.

3.2.8.1 Interpretive Guidance. See 2 of the Handbook.

3.2.8.2 Example(s). See 2 of the Handbook.

3.2.9 Records. The requirements of this Standard shall be supported by records documenting that established schedules and procedures are followed to maintain the adequacy of all M&TE. The records for M&TE requiring calibration shall include an individual record of calibration or verification, or other means of control, providing a description or identification of the item, calibration interval, date calibrated, identification of the calibration source, calibration results (data and/or condition status) and calibration action taken (adjusted, repaired, new value assigned, derated, etc.).

3.2.9.1 Interpretive Guidance. Records provide objective evidence that the laboratory is adhering to calibration schedules. They may be used to document instrument traceability. Records also provide a history of instrument stability and reliability which may be evaluated and used as a basis for adjustment of calibration intervals.

The Standard does not prescribe the length of time such records should be retained by the supplier. However, it may be of mutual benefit to both the customer and the supplier to retain the records as long as the M&TE is used on current contracts.

3.2.9.2 Example(s). Adequate calibration records are kept by the supplier for all M&TE. Records may be in a format developed at the supplier's discretion, but must be kept in a manner readily available for use by authorized personnel. The file may be in electronic media, such as computer records. A supplier's record system readily reveals the following data for all M&TE used by the supplier to determine compliance to contract requirements:

1) Identification of each piece of M&TE.
2) Current calibration interval and date of last calibration.
3) Calibration source (laboratory).
4) Calibration procedure used.
5) Results of previous calibrations such as condition found, (in-tolerance or out-of-tolerance), measured value if a fixed measurement standard, and any limitations of use.
6) Actions taken as a result of calibration such as any adjustments or corrections made, any repairs performed or parts replaced.
7) Any pertinent occurrences not directly related to periodic calibration, such as operational failures and erratic behavior.

3.2.10 Calibration Status. M&TE shall be labeled to indicate calibration or verification status. The label shall identify specific date calibrated (day, month, year, Julian date, or equivalent) and the specific calibration due date or usage equivalent. Items not calibrated to their full capability or which have other limitations of use, shall be labeled or otherwise identified as to the limitations. When it is impractical to apply a label directly to an item, the label may be affixed to the instrument container or some other suitable means may be used to reflect calibration status. Tamper-resistant seals are affixed to operator accessible controls or adjustments which if moved will invalidate the calibration. The supplier shall provide instructions for the disposition of equipment with broken tamper-resistant seals.

3.2.10.1 Interpretive Guidance. Each piece of M&TE should be labeled to provide a visual indication of its calibration status.

The label indicates date last calibrated, date due for calibration, and any known limitations of use. In addition, instruments overdue for calibration should be clearly marked to prevent use. While some suppliers may use relatively sophisticated labeling systems (e.g., bar codes and light beam reading devices) to provide instrument identification, it is still required that the calibration status (as indicated above) be visually presented. Operator accessible controls or adjustments that could invalidate the calibration require sealing to prevent tampering.

3.2.10.2 Example(s). Each piece of M&TE used by the supplier, whether supplier owned or leased, customer owned or leased, or personally owned by the supplier's employees, displays current calibration status, in terms of date calibrated, date calibration due, and any use limitations. The method of expressing calibration dates is left to the supplier; however, the dates are explicit. When labels are used as the means of indicating calibration status, the labels are distinctive and located on the instrument so as to be readily visible.

When it is impractical to apply labels directly to the instrument (such as gage blocks or mass standards), the label is applied to the container or is otherwise accessible to the user.

Some instruments, especially measurement standards that require reference to a certificate or report of calibration to be used are appropriately labeled.

The supplier has affixed tamper-resistant seals to operator accessible controls or adjustments on the M&TE which if moved could affect the calibration.

Responsibility for identifying the instruments requiring such seals rests with the supplier based on his knowledge of how the instruments are used in support of the contract. Such items should be removed from use if the seals are broken or otherwise compromised.

The supplier's documented calibration/verification system required in the Standard contains a complete description of the calibration status labels to assure understanding on the part of the users of M&TE and the calibration laboratory. The use of the tamper resistant seals on operator accessible controls and adjustments, and disposition of M&TE on which such seals are broken, is also included in the system documentation. When M&TE is calibrated by other than the supplier, and different labels are used, the labels should meet the requirements of the Standard and be described in the calibration/verification system description.

3.2.11 Control of Subcontractor Calibration. The supplier is responsible for assuring that the subcontractors calibration/verification system conforms to 2 and 3 of this Standard to the degree necessary to assure compliance with contractual requirements. Accreditation of a laboratory to 2 of this Standard by a third party activity acceptable to the customer may serve as the basis for compliance with this requirement.

3.2.11.1 Interpretive Guidance. All measurements and calibrations performed outside the supplier's plant, which may affect the quality or compliance with requirements of supplies or services presented to the Customer for acceptance, should be subject to the requirements of the Standard. The subcontractor could be a supplier that uses M&TE to test parts or products to be delivered to the supplier, or a calibration or standards laboratory providing calibration services for the supplier's M&TE. In either instance, the supplier has the responsibility to impose the applicable requirements and/or to assure that the subcontractor is in compliance with this Standard.

3.2.11.2 Example(s). The supplier has imposed appropriate requirements on subcontractors (including suppliers and vendors) necessary to assure compliance with this Standard. The strongest requirement by the supplier would be incorporation of the Standard in the subcontract. A lesser requirement, which might be as effective depending on the circumstances, would be incorporation of only portions of the Standard in the contract or incorporation of comparable requirements as fitting.

The supplier will review or audit the subcontractor to assure compliance with this Standard or whatever specific requirements were imposed. Results of the supplier's reviews should be available.

The subcontractor, especially those providing calibration services, may already be subject to the provisions of this Standard and undergone assessments or audits by an accrediting or other customer approved body. If available to the supplier, the results of such assessments or

audits of the subcontractor may be useful in assessing compliance to the supplier's specific requirements. However for previous audits or assessments to be meaningful, they should have covered the same or very similar measurement and calibration requirements as those of the supplier's. Also, the previous audit/assessment findings should still be valid. The use of previous assessment or audit result does not relieve the supplier of the responsibility to assure the subcontractor's compliance to requirements.

3.2.12 Storage and Handling. M&TE shall be handled, stored, and transported in a manner which shall not adversely affect the calibration or condition of the equipment.

3.2.12.1 Interpretive Guidance. Proper storage, handling and transportation of M&TE are essential to assure that required accuracy and reliability are maintained. Vibration, shock, temperature variances, humidity and dust are only some of the factors that could have an adverse impact on the capability of the instruments. The supplier must describe the proper methods of handling, transporting, and storing of M&TE in his calibration/verification system description.

3.2.12.2 Example(s). A procedure for handling, transporting and storing M&TE is in place. The following factors are included in the procedure as appropriate:

1) Equipment is appropriately protected prior to and during transportation.
2) Handling of equipment during transportation or use follows manufacturer's recommendations and good commercial practice.
3) Storage areas for equipment provide acceptable conditions of temperature, humidity, and other pertinent factors to preclude deterioration.
4) The supplier's documented procedures require that instances of improper handling, storage, or transportation be investigated for adverse effects on the M&TE and appropriate corrective action is taken.

4 PART IV: EXAMPLES

4.1 Example 1: Report of Calibration and Certificates

See Example 1.

4.2 Example 2 : Certificate of Calibration

See Example 2.

Report of Calibration
(Example 1)

Date of Issue: May 1, 2007

[Name of the Calibration Laboratories]
[Address of the calibration laboratory]

Calibration Item:	_____	Submitted By:	_____
Manufacturer:	_____	Company:	_____
Model No.	_____	Address:	_____
Serial No.	_____	Telephone:	_____
Control No.	_____		

The item to be calibrated was received in good condition, in tolerance, and required no special preparation prior to measurement in this laboratory.

Measurements were made using [name of the instrument(s)] by [name of the methods or procedure] traceable to the National Institute of Standards and Technology (NIST).

The reported value(s) and uncertainties resulting from the measurement process are:

[Parameter calibrated]	[Unit]	[Value]	[Uncertainty]*

*Coverage factor *k=2*

Reference temperature: 100.00 ^{o}C ± 0.005 ^{o}C
Room ambient conditions: Temperature: 23 ^{o}C ± 1 ^{o}C;
Relative humidity: 45% RH ± 5% RH

Date of Issue: May 1, 2007

Equipment and Procedures Used:

Description	ID Number	Exp./Issue Date
Blackbody, M340	10025	12/20/07
[Other equipment used]	10038	1/12/08
[Calibration procedures used]	[xxx]	6/30/02

Notes

1) Three sets of ten measurements over a period of 90 min were made on the test [calibration item] on each alternate day between [starting date] and [ending date] at a nominal [parameter calibrated] of [number] [unit] with indicated reference temperature of 100 ^{o}C.

2) The [calibration parameter] value reported is the grand average of the three sets of ten measurements corrected to ……

3) The uncertainty reported is two times (*k=2*) the combined standard uncertainty including the random variance of the three sets of measurements, the uncertainty of the reference temperature, and those of the [xxx] used in the calibration, expressed as variances. Other possible sources of uncertainty such as [xxx] relative to ambient temperature were negligible.

4) The standards and calibration program of the [name of the calibration laboratories] complies with the requirements of ANSI/MIL-STD-45662A/[This Standard] and is approved by the US Calibration Laboratory Approval Agency (USCLAA) for the parameter(s) listed.

Date of Issue: May 1, 2007

General Conditions

Unless Otherwise Stated:

- No allowance has been made for the instability of the test device due to use, time, etc.. such allowance would be made by the customer as needed.
- No sampling plan or other sampling process was used for this calibration and the result(s) reported herein apply only to the calibration item described above.
- There are no special limitations of use imposed on the calibration item.
- This report may not be reproduced, excepted in full, unless permission for the publication of an approved abstract is obtained in writing from the calibrating organization issuing this report.

Measurement Performed by:		Approved by:	
Name		Name:	
Title:	Metrology Technician	Title:	Laboratory Manger
Cal. Completion Date:		Phone	

Certificate of Calibration
(Example 2)

Date of Issue: May 1, 2007

[Name of the Calibration Laboratories]
[Address of the calibration laboratory]

Calibration Item:	_____	Submitted By:	_____
Manufacturer:	_____	Company:	_____
Model No.	_____	Address:	_____
Serial No.	_____	Telephone:	_____
Control No.	_____		

Item Condition/Special Customer Requirements

As Received		As Left	
[X]	In Tolerance*	[X]	In Tolerance*
[ ]	Out of Tolerance*	[ ]	Out of Tolerance*
[ ]	Inoperative	[ ]	Inoperative
[X]	Limited Calibration**	[X]	Limited Calibration**
		[ ]	Adjusted

* Per referenced calibration procedure.
** Limited by customer

Remarks: Only [calibration parameter] calibrated per customer request.

Room Ambient Conditions: Temperature 23 ^{o}C±1 ^{o}C, relative humidity 45% RH ±5% RH.
Procedure Used: xx-xxxxxx-x

Date of Issue: May 1, 2007

Notes / General Conditions:

a. The standards and calibration program of [*name of the calibration laboratory*] complies with the requirement of ANSI/MIL-STD-45662A/[This Standard].

b. Unless otherwise stated or provided for, the following apply.

(1) Standards used in this calibration, described in the referenced calibration procedure with associated uncertainties or tolerances, are traceable to the National Institute of Standards and Technology (NIST).
(2) There are no special limitations of use imposed on the calibration item.
(3) This report may not be published, except in full, unless permission for the publication of an approved abstract is obtained in writing from the calibrating organization issuing this report.

Measurement Performed by:		Approved by:	
Name		Name:	
Title:	Metrology Technician	Title:	Laboratory Manger
Cal. Completion Date:		Phone	

5 PART V: SAMPLE CHECKLIST FOR EVALUATION OF CALIBRATION SYSTEMS

The sample checklist provided on the following pages was created to serve as an aid for the evaluation of a calibration laboratory's compliance with the *Handbook of Electro-Optical Measurements*, "*General Requirements for the Competence of Calibration Laboratories*".

The checklist is keyed to the EOSPA for guidance only and should not be viewed as a requirements document. It is not intended to add to, or subtract from, nor in anyway to modify the EOSPA standard proper. However, other items may be added based on the scope and/or quality system under review.

The Control *Number* is provided to facilitate the entry of a unique evaluation identifier, *e.g., Control Number 123* or *ABC*. The *Doc. No.* is provided to annotate document number, if applicable, of the documentation describing the system being evaluated. The *Objective Evidence* column is provided to allow the annotation of those documents which may address a specific area of the *EOSPA*. The "*S/U/N*" column may be used to note the level of compliance: "*S*" for *Satisfactory*; "*U*" for *Unsatisfactory*; "*N*" for *Needs Improvement*. A remark column is provided in the checklist for the annotation of comments as appropriate.

SAMPLE CHECKLIST FOR EVALUATION OF CALIBRATION SYSTEMS

HANDBOOK OF ELECTRO-OPTICAL MEASUREMENTS

GENERAL REQUIRMENTS FOR CALIBRATION LABORATORIES AND MEASURING / TEST EQUIPMENT (M&TE)

Control No. _____ **Auditing Agency** _____

Organization _____ **Audit Evaluator** _____

Calibration System Description:

Doc. No. **Audit Date**

PART II: General Requirements for the Competence of Calibration Laboratories.
Chapter II of the *Handbook of Electro-Optical Standard for Applications (EOSPA*) applies to calibration laboratories in the development and implementation of their quality systems.

EOSPA Evaluation Factors	Objective Evidence	S	U	N	Remarks
2.1 Laboratory Organization and Management 2.1.1 Legal Identity The laboratory shall be legally identifiable. It shall be organized and shall operate in such a way that its permanent, temporary, and mobile facilities meet the requirements of EOSPA.					
2.1.2 Managerial Staff The laboratory shall have managerial staff with the authority and resources needed to discharge their duties.					

EOSPA Evaluation Factors	Objective Evidence	S	U	N	Remarks
2.1.3 Personnel The laboratory shall have arrangements to ensure that its personnel are free from any undue pressures which might adversely affect the quality of their work.					
2.1.4 Organization Structure The laboratory shall be organized in such a way that confidence in its independence of judgment and integrity is maintained at all times.					
Error! Reference source not found.Error! Reference source not found.2.1.5 **Error! Reference source not found.Error! Reference source not found.**Documentation The laboratory shall specify and document the responsibility, authority and interrelation of all personnel who manage, perform or verify work affecting the quality of calibrations.					
2.1.6 Supervision The laboratory shall provide supervision by persons familiar with the calibration methods and procedures, the objective of the calibration and the assessment of the results. Management practices shall be such as to ensure adequate supervision.					
2.1.7 Technical Manager The laboratory shall have a technical manager (however named) who has overall responsibility for the technical operations.					
2.1.8 Quality Manager The laboratory shall have a quality manager (however named) who has responsibility for the quality system and its implementation. The quality manager shall have direct access to the highest level of management at which decisions are taken on laboratory policy or resources, and to the technical manager. In some laboratories, the quality manager may also be the technical manager or deputy technical manager.					

EOSPA Evaluation Factors	Objective Evidence	S	U	N	Remarks
2.1.9 Designated Alternates The laboratory shall designate alternates in case of absence of the technical or quality manager.					
2.1.10 Policy and Procedures The laboratory shall have, where relevant, have documented policy and procedures to ensure the protection of customer's confidential information and proprietary rights.					
2.1.11 Measurement Assurance Programs The laboratory shall, where appropriate, participate in inter laboratory comparisons and proficiency testing programs.					
2.2 Quality System, Audit, and Review 2.2.1 Quality System The laboratory shall establish and maintain a quality system appropriate to the type, range and volume of calibration activities it undertakes. The elements of this system shall be documented. The quality documentation shall be available for use by the laboratory personnel. The laboratory shall define and document its policies and objectives for, and its commitment to, good laboratory practice and quality of calibration services. The laboratory management shall ensure that these policies and objectives are documented in a quality manual and communicated to, understood, and implemented by all laboratory personnel concerned. The quality manual shall be maintained current under the responsibility of the quality manager.					
2.2.2 Quality Manual The quality manual and related documentation shall state the laboratory's policies and operational procedures established in order to meet the requirements of this Standard.					
2.2.2.1-1 A quality policy statement, including objectives, by top management					

EOSPA Evaluation Factors	Objective Evidence	S	U	N	Remarks
2.2.2.1-2 The organization and management structure of the laboratory, its place in any parent organization, related organization charts					
2.2.2.1-3 The relations between management, technical operations, support services and the quality system					
2.2.2.1-4 Procedures for control and maintenance of documentation					
2.2.2.1-5 Job descriptions of key staff and reference to descriptions of other staff					
2.2.2.1-6 Identification of the approved signatories of the laboratory					
2.2.2.1-7 The laboratory's procedures for achieving traceability of measurements					
2.2.2.1-8 The laboratory's scope of calibrations and/or verifications					
2.2.2.1-9 Arrangements for ensuring that the laboratory reviews all new work to ensure that it has the appropriate facilities and resources before commencing such work					
2.2.2.1-10 Reference to the calibration and verification procedures used					
2.2.2.1-11 Procedures for handling calibration and verification items					
2.2.2.1-12 Reference to the major equipment and reference measurement standards used					
2.2.2.1-13 Reference to procedures for calibration, verification and maintenance of equipment used					
2.2.2.1-14 Reference to quality assurance practices including inter laboratory comparisons, proficiency testing programs, use of reference materials, and internal quality control schemes					

EOSPA Evaluation Factors	Objective Evidence	S	U	N	Remarks
2.2.2.1-15 Procedures to be followed for feedback and corrective action whenever measurement discrepancies are detected, or departures from documented policies and procedures occur					
2.2.2.1-16 The laboratory management arrangements for exceptionally permitting departures from documented policies and procedures or from standard specifications					
2.2.2.1-17 Procedures for dealing with complaints					
2.2.2.1-18 Procedures for protecting confidentiality and proprietary rights					
2.2.2.1-19 Procedures for audit and review					
2.2.2.1-20 A statement of the lab's policy for establishing and changing calibration intervals for equipment it controls					
2.2.2.1-21 A statement of the laboratory's policy concerning the technique(s) to be used for determining measurement uncertainty and calibration/verification adequacy					
2.2.3 Quality Audit The laboratory shall arrange for audits of its activities at appropriate intervals to verify that its operations continue to comply with the requirements of the quality system. Such audits shall be carried out, wherever possible, by trained and qualified staff who are independent of the activity to be audited. Where the audit findings cast doubt on the correctness of validity of the laboratory's calibrations results, the laboratory shall take immediate corrective action and shall immediately notify, in writing, any client whose work may have been affected.					

EOSPA Evaluation Factors	Objective Evidence	S	U	N	Remarks
2.2.4 Quality System Review The quality system adopted to satisfy the requirements of this Standard shall be reviewed at least once a year by the management to ensure its continuing suitability and effectiveness and to introduce any necessary changes or improvements.					
2.2.5 Documentation All audit and review findings and any corrective actions that arise from them shall be documented. The person responsible for quality shall ensure that these actions are discharged within the agreed timeframe.					
2.2.6 Quality Check In addition to periodic audits the laboratory shall ensure the quality of results provided to customers by implementing checks. These checks shall be reviewed and shall include, as appropriate, but not be limited to:					
2.2.6.1 internal quality control using, wherever possible, statistical techniques					
2.2.6.2 participation in proficiency testing or other inter laboratory comparisons					
2.2.6.3 regular use of certified reference materials and/or in-house quality control using reference materials					
2.2.6.4 replicate measurements using the same or different methods					
2.2.6.5 correlation of results for different characteristics of an item					

EOSPA Evaluation Factors	Objective Evidence	S	U	N	Remarks
2.3 Personnel 2.3.1 Staff Size The calibration laboratory shall have sufficient personnel with the necessary education, training, technical knowledge and experience for their assigned functions.					
2.3.2 Staff Training The calibration laboratory shall ensure that the training of its personnel is kept up-to-date consistent with employee assignments and development.					
2.3.3 Staff Records Records on the relevant qualifications, training, skills and experience of the technical personnel shall be maintained and be available to the laboratory.					
2.4 Accommodation and Environment 2.4.1 Laboratory Environmental Conditions Laboratory accommodation (facilities), calibration areas, energy sources, lighting, temperature, humidity, and ventilation shall be such as to facilitate proper performance of calibrations/verifications.					
2.4.2 Experiment Environmental Conditions The environment in which these activities are undertaken shall be specified and not invalidate the results or adversely affect the required uncertainty of measurement. Particular care shall be taken when such activities are undertaken at sites other than the permanent laboratory premises.					
2.4.3 Monitor, Control, and Record The laboratory shall effectively monitor, control and record environmental conditions as appropriate. Due attention shall be paid, for example, to biological sterility, dust, electromagnetic interference, humidity, line voltage, temperature, and sound and vibration levels, as appropriate to the calibrations concerned.					

EOSPA Evaluation Factors	Objective Evidence	S	U	N	Remarks
2.4.4 Sub Zoning There shall be effective separation between neighboring areas when the activities therein are incompatible.					
2.4.5 Access Control Access to and use of all areas affecting the quality of these activities shall be defined and controlled.					
2.4.6 Housekeeping Adequate measures shall be taken to ensure good housekeeping in the laboratory.					
2.5 Equipment and Reference Materials 2.5.1 Equipment Availability The laboratory shall be furnished with all items of equipment (including reference materials) required for the correct performance of calibrations/verifications. In those cases where the laboratory needs to use equipment outside its permanent control, it shall ensure that the relevant requirements of this Standard are met.					
2.5.2 Equipment Maintenance All equipment shall be properly maintained. Maintenance procedures shall be documented. Any item of the equipment which has been subjected to overloading or mishandling, or which gives suspect results, or has been shown by verification or otherwise to be defective, shall be taken out of service, clearly identified and wherever possible stored at a specified place until it has been repaired and shown by calibration or verification to perform satisfactorily. The laboratory shall examine the effect of this defect on previous calibrations.					
2.5.3 Equipment Labels Each item of equipment including reference materials shall, when appropriate, be labeled, marked or otherwise identified to indicate its calibration status.					

EOSPA Evaluation Factors	Objective Evidence	S	U	N	Remarks
2.5.4 Equipment Records Records shall be maintained of each item of equipment and all reference materials significant to the calibrations/verifications performed.					
2.5.4a. The name of the item of equipment.					
2.5.4b. The manufacturer's name, type identification, and serial number or other unique identification.					
2.5.4c. Current location, where appropriate.					
2.5.4dd. Where applicable, dates and results of calibration and/or verifications and date or criteria when the calibration and/or verification expires.					
2.5.4e. Details of maintenance carried out to date and planned for the future.					
2.5.4f. History of any damage, malfunction, modification or repair.					
2.5.4g. Measured value observed for each parameter found to be out of tolerance during calibration/verification.					
2.6 Measurement Traceability and Calibration					
2.6.1 Calibration System All measuring/testing equipment having an effect on the accuracy or validity of calibrations shall be calibrated and/or verified before being put into service. The laboratory shall have an established program for the calibration and verification of its measuring and test equipment to ensure the recall or removal from service of any standard or equipment which has exceeded its calibration interval or is otherwise judged to be unreliable.					

EOSPA Evaluation Factors	Objective Evidence	S	U	N	Remarks
2.6.2 Calibration Traceability The overall program of calibration and/or verification of equipment shall be designed and operated so as to ensure that, wherever applicable, measurements made by the laboratory are traceable to national, international, or intrinsic standards of measurements where available. Calibration certificate and/or report shall, wherever applicable, state the traceability to national, international, or intrinsic standards of measurements and shall provide the measurement results and associated uncertainty of measurement and/or a statement of compliance with an identified metrological specification.					
2.6.3 Alternatives Where traceability to international, national, or intrinsic standards of measurement is not available, traceability requirements may be satisfied by:					
2.6.3a. Participation in a suitable program of interlaboratory comparisons or proficiency testing.					
2.6.3b. Internationally accepted standards in the field concerned.					
2.6.3c. Suitable reference materials.					
2.6.3d. Ratio or reciprocity-type measurements					
2.6.3e. Mutual consent standards which are clearly specified and mutually agreed upon by all parties concerned.					
2.6.4 Reference Standards Usage Reference standards of measurements held by the laboratory shall be used for calibration or verification only and for no other purpose, unless it can be demonstrated that their performance as reference standards has not been invalidated.					

EOSPA Evaluation Factors	Objective Evidence	S	U	N	Remarks
2.6.5 Reference Standards Calibration Reference standards of measurement shall be calibrated by a competent body that can provide traceability. There shall be a program of calibration and verification for reference standards.					
2.6.6 Additional Validation Where relevant, reference standards, measuring and test equipment shall be subject to in-service checks between calibrations and verifications.					
2.6.7 Reference Material Reference materials shall, where possible, be traceable to national or international standards of measurements, or to national or international standard reference materials.					
2.7 Calibration Methods and Procedures 2.7.1 Documentation The laboratory shall have documented instructions on the use and operation of all relevant equipment, on the handling and preparation of items, and for calibrations/verifications, where the absence of such instructions could jeopardize the calibrations/verifications. All instructions, standards, manuals, and reference data relevant to the work of the laboratory shall be maintained up-to-date and be readily available to the staff.					
2.7.2 Use of Calibration Methods and Procedures The laboratory shall use appropriate methods and procedures for all calibrations/verifications and related activities within its responsibility (including, but not limited to, sampling, handling, transport and storage, preparation of items, estimation of uncertainty of measurement and analysis of calibration data).					

EOSPA Evaluation Factors	Objective Evidence	S	U	N	Remarks
2.7.2a Calibration procedures shall contain the required range and tolerance or uncertainty of each item or unit parameter being calibrated or verified. In addition, the procedures shall contain the generic description of the measurement standards and equipment needed with the required parameter, range, tolerances or uncertainties, and specifications for performing the measurement of the calibration or verification, and/or representative types (manufacturer, model, option) that are capable of meeting the generic description for the measurement standards. The procedures shall be consistent with the accuracy required, and with any standard specifications relevant to the calibrations/verifications concerned.					
2.7.2b The laboratory shall ensure that the calibration uncertainties are sufficiently small so that the adequacy of the measurement is not affected. Well defined and documented measurement assurance techniques or uncertainty analyses may be used to verify the adequacy of a measurement process. If such techniques or analyses are not used, then the collective uncertainty of the measurement standards shall not exceed 25% of the acceptable tolerance (e.g., manufacturer's specification) for each characteristic of the measuring and test equipment being calibrated or verified.					
2.7.3 Standard Calibration Methods and Procedures. Where methods are not specified, the laboratory shall, wherever practical, select methods that have been published in international or national standards, those published by reputable technical organizations or in relevant scientific texts or journals.					

EOSPA Evaluation Factors	Objective Evidence	S	U	N	Remarks
2.7.4 Alternatives Where it is necessary to employ methods that have not been well established, these shall be subject to agreement with the customer, be fully documented and validated, and be available to the customer or other recipients of the relevant reports.					
2.7.5 Sampling Methods Where sampling is carried out as part of the calibration method, the laboratory shall use documented procedures and appropriate statistical techniques to select the samples.					
2.7.6 Calculations and Data Transfers Calculations and data transfers shall be subject to appropriate checks.					
2.7.7 Data Automation Where computers or automated equipment are used for the capture, processing, manipulation, recording, reporting, storage or retrieval of calibration data, the laboratory shall ensure that:					
2.7.7a a. The requirements of this Standard are followed.					
2.7.7b b. Computer software is documented and adequate for use.					
2.7.7c c. Procedures are established and implemented for protecting the integrity of data. Such procedures shall include, but are not limited to, integrity of data entry or capture, data storage, data transmission and data processing.					
2.7.7d4) Computers and peripheral equipment used for calibration processes have recommended environmental operating needs and routine maintenance procedures that ensure their continued operation.					

EOSPA Evaluation Factors	Objective Evidence	S	U	N	Remarks
2.7.7e. It establishes and implements appropriate procedures for the maintenance of security of data including the prevention of unauthorized access to, and the unauthorized amendment of, computer records.					
2.7.8 Consumable Materials Documented procedures shall exist for the purchase, reception and storage of consumable materials used for the technical operations of the laboratory that can affect the results of calibrations.					
2.8 Handling of Calibration Items 2.8.1 Documentation The laboratory shall have a documented system for uniquely identifying the items to be calibrated, to ensure that there can be no confusion regarding the identity of such items at any time.					
2.8.2 Records Upon receipt of the calibration item, any abnormalities or departures from standard condition as prescribed in the relevant calibration method shall be recorded. Where there is any doubt as to the item's suitability for calibration, where the item does not conform to the description provided, or where the calibration required is not fully specified, the laboratory shall consult the customer for further instruction before proceeding. The laboratory shall establish whether the item has received all necessary preparation, or whether the customer requires preparation to be undertaken or arranged by the laboratory.					
2.8.3 Handling The laboratory shall have documented procedures and appropriate facilities to avoid deterioration or damage to the calibration item, during storage, handling, preparation, and calibration; any relevant instructions provided with the item shall be followed. Where items have to be stored or conditioned					

EOSPA Evaluation Factors	Objective Evidence	S	U	N	Remarks
under specific environmental conditions, these conditions shall be maintained, monitored and recorded where necessary. Where a calibration item or portion of an item is to be held secure (for example, for reasons of record, safety or value, or to enable check calibrations to be performed later), the laboratory shall have storage and security arrangements that protect the condition and integrity of the secured items or portions concerned.					
2.8.4 Safety The laboratory shall have documented procedures for the receipt, retention or safe disposal of calibration items, including all provisions necessary to protect the integrity of the laboratory.					
2.8.5 Seals Tamper-resistant seals shall be affixed to operator accessible controls or adjustments on measurement standards or measuring and test equipment which, if moved, will invalidate the calibration. The laboratory's calibration system shall provide instructions for the use of such seals and for the disposition of equipment with damaged or broken seals.					
2.9 Records 2.9.1 Laboratory Records The laboratory shall maintain a record system to suit its particular circumstances and comply with any applicable regulations. The records for each calibration shall contain sufficient information to permit the repetition of the calibration. The records shall include the identity of personnel involved in preparation and calibration.					
2.9.2 Bookkeeping All records (including those pertaining to calibration equipment), certificates, and reports shall be safely stored and held secure and in confidence to the customer for the period specified in the quality manual.					

EOSPA Evaluation Factors	Objective Evidence	S	U	N	Remarks

**** NOTHING FOLLOWS ****